Appendix D: Analysis of Pest Risk Potential for Representative Species

The pest species or complexes listed in table D–1 were selected for detailed analyses of pest risk potential for entry with shipments containing SWPM and subsequent establishment in the United States. These species and complexes are meant to serve as examples of the kinds of exotic pest threats that exist in relation to importation of SWPM to the United States but are not inclusive of all potential exotic pest threats, either known or unknown. These pest species and complexes represent various combinations of regional distribution (i.e., temperate or tropical and subtropical countries of origin), host type (i.e., conifers or hardwoods), and pest habitat (in deep wood, under bark, or on bark). Some species represent more than one combination of criteria. The selected species also represent a range of organism types, including insects and fungi. Individual analyses for each species or complex listed in table D–1 are presented in this section.

Table D–1. Representative pest species or groups selected for analysis

Pest species	Regional distribution	Host type	Pest habitat
Anoplophora glabripennis (wood borer)	Temperate	Hardwoods	In deep wood
Aradus cinnamomeus (true bug)	Temperate	Conifers	On bark
Armillaria/Phellinus/ Ganoderma spp. (fungi)	Temperate Tropical/subtropical	Hardwoods Conifers	In deep wood
Ceratocystis fimbriata (fungus)	Tropical/subtropical	Hardwoods	In deep wood Under bark
Erythricium (*Corticium*) *salmonicolor* (fungus)	Tropical/subtropical	Hardwoods	In deep wood Under bark On bark
Heterobasidion spp. (fungi)	Temperate	Conifers Hardwoods	In deep wood
Hylurgus ligniperda/ Leptographium spp. (bark beetle/fungi)	Temperate	Conifers	Under bark
Ips typographus/ *Ceratocystis polonica* (bark beetle/fungus)	Temperate	Conifers	Under bark
Kalotermitidae spp. (termites)	Temperate Tropical/subtropical	Hardwoods Conifers	In deep wood

Table D–1 Continued. Representative pest species or groups selected for analysis

Pest species	Regional distribution	Host type	Pest habitat
Lymantria dispar (Asian biotype) (moth)	Temperate	Hardwoods Conifers	On bark
Lymantria monacha (moth)	Temperate	Conifers Hardwoods	On bark
Ophiostoma/Ceratocystis spp. (fungi)	Temperate Tropical/subtropical	Conifers Hardwoods	In deep wood Under bark
Orthotomicus erosus (bark beetle)	Temperate Tropical/subtropical	Conifers	Under bark
Phellinus noxious (fungus)	Tropical/subtropical	Hardwoods Conifers	In deep wood
Pterophylla beltrani (cricket)	Tropical/subtropical	Hardwoods Conifers	On bark
Rhinotermitidae spp. (termites)	Temperate Tropical/subtropical	Hardwoods Conifers	In deep wood
Sarsina violascens (moth)	Tropical/subtropical	Hardwoods	On bark
Scolytus intricatus (bark beetle)	Temperate	Hardwoods	Under bark
Sirex noctilio/ Amylostereum areolatum (woodwasp/fungus)	Temperate	Conifers	In deep wood

Wood Pathogens

Root and Stem Rots

Assessor—Harold Burdsall

Scientific Names of Pests—*Armillaria* spp., *Phellinus* spp., *Ganoderma* spp. (Basidiomycetes).

Scientific Names of Hosts—Many conifer and deciduous tree species, both temperate and tropical.

Distribution—Worldwide.

Summary of Natural History and Basic Biology of the Pests—*Armillaria, Phellinus,* and *Ganoderma* species are being treated together here because they function similarly in the ecosystem and mitigation procedures taken against one will be equally effective or ineffective against all. Species of heart-rot and root-rot fungi represented by the genera mentioned above are of worldwide distribution, and many of the species are not found in the United States. Nearly every country in the world is home to several species exotic to the United States (Buchanan and Wilkie 1995, Larsen and Cobb 1990, Volk and Burdsall 1995).

Exotic *Armillaria* species are well known throughout the world (see table D–2). For example in South America, *Armillaria procera, A. novo-zealandica,* and *A. luteobubalina* are well known for pathogenic capability (Kile et al. 1991). All species examined to date have the ability to cause disease in some situations, frequently in a broad range of host species. They are also adept at surviving as saprophytes in dead wood for long periods of time (Kile 1980, Rishbeth 1972, Shaw 1975). In Africa, *Armillaria heimii* and *Armillaria fuscipes* cause extensive problems in woody plants. *Armillaria heimii* is particularly problematic because of its ability to complete the life cycle from a single spore. The same is reported for the African form of *A. mellea,* which has been classified the subspecies *A. mellea* ssp. *africana* (Guillaumin et al. 1991). This characteristic distinguishes it from the North American and European strains of the species. Further research will probably demonstrate the need to reclassify *A. mellea* ssp. *africana* as a separate species, as has occurred with *Heterobasidion* groups in Europe. Even Europe has its endemic species of *Armillaria, A. borealis.* In Japan, two new species have been recently discovered (Cha et al. 1994), the East Indies have their own species, and it is suspected that this is the case in numerous countries throughout the world. How these species would function in the North American ecosystem is of course not obvious, but to date all are known to have some pathogenic capability that would accompany them.

The genus *Phellinus* is equally well represented throughout the world (see table D–3). The species differ substantially from one country to another, and new species are being described regularly. Europe is home to numerous *Phellinus* species not found in the United States. One such species, *P. torulosus*, was considered to be disjunctly present in Europe and Arizona (Gilbertson and Burdsall 1972). It has recently been found to be distinct from the European taxon (D. Rizzo, personal communication). The species that is called *P. pini* in the United States is probably a different species from true *P. pini* in Europe (E. Hansen, personal communication). The other endemic European species of *Phellinus* are too numerous to mention (Ryvarden and Gilbertson 1994). The same is true of Africa, which has a wide variety of *Phellinus* species not occurring in the United States (Ryvarden and Johansen 1980). India (Sharma 1995), China (Larsen and Cobb 1990), and the republics of the former Soviet Union (Bondartzev 1953, Domanski 1965) also possess unique *Phellinus* species.

Species of *Ganoderma* are also potential pests. They cause root and butt rot of either conifers or hardwoods, depending on the species. Africa has species unknown in the United States (Baxter and Eicher 1995, Ryvarden and Johansen 1980), as does South America (Martinez et al. 1995), India (Bakshi 1971), Japan (Ito 1955), and China (Ji-Ding and Xiao-Qing 1995). In many of these countries *G. applanatum* and *G. lucidum* are reported to occur. These species also occur in the United States. However, recent studies using molecular techniques have demonstrated that the species being called by these names are not conspecific, and Taiwan, Argentina, Europe,

Table D–2. *Armillaria* species, hosts, and distribution

Root- and stem-rot species	Hosts	Distribution
Armillaria affinis (Singer) Volk & Burds.	Hardwoods	Central America, Caribbean
Armillaria mellea subsp. *africana* Guill.	Hardwoods	Africa
Armillaria borealis Marxm. and Korh.	Hardwoods	Europe
Armillaria calvescens Bérubé and Dessur.	Hardwoods	Eastern North America
Armillaria camerunensis (Henn.) Volk & Burds	?	Africa
Armillaria cepestipes Velen.	Hardwoods	Europe, North America
Armillaria duplicata (Berk.) Sacc.	?	India
Armillaria ectypa (Fr.) Emel	Hardwoods	Europe
Armillaria fellea (Hongo) Kile & Watl.	Hardwoods	Australia
Armillaria fumosa Kile & Watl.	Hardwoods, conifers	Australia
Armillaria fuscipes Petch	Hardwoods	India, Africa?
Armillaria gallica Marxm.& Romagn.	Hardwoods, conifers	North America, Europe, Japan
Armillaria gemina Bérubé and Dessur.	Hardwoods	Eastern North America
Armillaria griseomellea (Singer) Watl. & Kile	?	South America
Armillaria heimii Pegler	Hardwood, conifers	Africa
Armillaria hinnulea Kile & Watl.	Hardwoods	Australia
Armillaria jezoensis Cha and Igar.	Hardwoods	Japan
Armillaria limonea (G. Stev.) Boesew.	Hardwood, conifers	New Zealand
Armillaria luteobubalina Kile & Watl.	Hardwoods, conifers	Australia, South America?
Armillaria mellea (Vahl:Fr.) P. Kumm.	Hardwoods, conifers	North America, Europe, Asia
Armillaria melleo-rubens (Berk. & Curt.) Sacc.	?	Central America
Armillaria montagnei (Singer) Herink	?	South America, Europe?
Armillaria nabsnona Volk & Burds.	Hardwoods	Western North America
Armillaria novae-zelandiae (G. Stev.) Herink	Hardwoods, conifers	New Zealand, New Guinea, Australia, South America
Armillaria omnituens (Berk.) Sacc.	?	India
Armillaria ostoyae (Romagn.) Herink	Mainly conifers	North America, Europe
Armillaria pallidula Kile & Watl.	Conifers	Australia
Armillaria pelliculata Beeli	?	Africa
Armillaria procera Speg.	Hardwoods	South America
Armillaria puiggarii Speg.	Hardwoods	South America
Armillaria sinapina Bérubé & Desser.	Hardwoods, conifers	North America, Japan
Armillaria singula Cha & Igarashi	Hardwoods	Japan
Armillari sparrei (Singer) Herink	Hardwoods	South America
Armillaria tabescens (Scop.) Emel	Hardwoods, conifers	North America, Europe
Armillaria tigrenis (Singer) Volk & Burds.	Hardwoods	South America
Armillaria viridiflava (Singer) Volk & Burds.	Hardwoods	South America
Armillaria yungensis (Singer) Herink	Hardwoods	South America

Table D-3. *Phellinus* species, hosts, and distribution

Root- and stem-rot species	Hosts	Distribution
Phellinus acontextus Ryv.	*Abies* spp.	Nepal
Phellinus adamantinus (Berk.) Ryv.	Hardwoods	Southeast Asia, Indonesia, India, Thailand
Phellinus adhaerens Wright & Blumenf.	Hardwoods	Argentina
Phellinus allardii (Bres.)Ahmad	Hardwoods	Africa
Phellinus ampelinus Bond.	Hardwoods	Russia
Phellinus andinopatagonicus Wright & Desch.	*Nothofagus*, *Austrocedrus*	South America
Phellinus andinus Plank & Ryv.	Myrtaceae	Argentina
Phellinus apiahynus (Speg.) Rajch. & Wright	*Ocotea*	Argentina
Phellinus appositus (Lev.) Niem.	Hardwoods	Indonesia, Tjiboya
Phellinus calcitratus (Berk. & Curt.) Ryv.	Hardwoods	South America, Caribbean Islands
Phellinus caryophyllii (Racib.) Cunn.	Hardwoods	Indonesia, Australia, New Guinea
Phellinus chinensis (Pilat) Pilat	*Populus* spp.	China, Russia
Phellinus conchatus (Pers.:Fr.) Quél. Forms	Hardwoods	Worldwide
Phellinus durissimus (Lloyd) Roy	Hardwoods	African and American tropics
Phellinus glaucescens (Petch) Ryv.	Hardwoods	Africa, Malaysia
Phellinus hippophaecola Jahn	Hardwoods	Europe
Phellinus hoehnelii (Bres.) Ryv.	Hardwoods	Indonesia
Phellinus igniarius (L.:Fr.) Quél. Forms	Hardwoods	Europe, Scandinavia
Phellinus kravtzevii Schwars.	Hardwoods	Kazakhstan
Phellinus lamaensis (Murr.) Pat.	Hardwoods	China, Africa, Australia, Indonesia
Phellinus linteus (Berk. & Curt.) Teng	Hardwoods	Nicaragua, Mexico, Africa, tropical South America
Phellinus lividus (Kalchbr.) Ahmad	Hardwoods	India, Australia, South American tropics
Phellinus lonicerinus (Bond.) Pilat	*Lonicera* spp.	Turkestan, Kazakhstan
Phellinus lukinsii Walters	*Eucalyptus* spp.	Australia
Phellinus melanoderma (Pat.) O. Fidalgo	Hardwoods	Southeast Asia, Philippines, Ceylon, Brazil
Phellinus neoquercinus M. Larsen	*Quercus* spp.	China
Phellinus nothofagi (Cunn.) Ryv.	*Nothofagus* spp.	New Zealand
Phellinus noxius (Corner) Cunn.	Hardwoods	Circumglobal tropics
Phellinus pachyphloeus (Pat.) Pat.	Hardwoods, conifers	Circumglobal tropics
Phellinus pilatii Cerny	*Populus* spp.	Europe, Middle East
Phellinus poeltii Ryv.	*Abies* spp.	Himalaya, Nepal
Phellinus populicola Niem.	*Populus* spp.	North Europe
Phellinus pouzarii Kotlaba	*Abies* spp.	Czech Republic
Phellinus quercinus Bond. & Ljub.	*Quercus* spp.	Russia
Phellinus resinaceus Kotl. & Pouz.	*Eucalyptus* spp.	Australia, New Guinea
Phellinus rhamni (Bond.) Jahn	Hardwoods	Southern Europe
Phellinus ribis (Schmüm.):Fr.) Quél. Forms	Hardwoods	Europe, Russia
Phellinus rimosus (Berk.) Pilat	Hardwoods	Tasmania, Mexico, Puerto Rico
Phellinus rudis (Berk.) Zeng	Hardwoods	China, India, Australia
Phellinus stratosus Pat.	Hardwoods	Laos

Table D-3 Continued. *Phellinus* species, hosts, and distribution

Root- and stem-rot species	Hosts	Distribution
Phellinus syringeus Teng	*Syringa* spp.	China
Phellinus tawhai (Cunningham) Cunningham	*Nothofagus* spp.	New Zealand
Phellinus terminaliae (Ito & Ito) M. Larsen	Hardwoods	Japan
Phellinus torulosus (Pers.) Bourd. & Galz.	Hardwoods	Europe
Phellinus usuriensis Bond. & Ljub.	Hardwoods	Russia

India, China, Hong Kong, and the Philippines all possess taxa biologically different from those in the United States even though they may carry the same name (Moncalvo et al. 1995).

Armillaria and *Phellinus* species exist to one degree or another as rhizomorphs or mycelium (possibly chlamydospores) either in the soil itself or in woody debris and stumps. Recent data indicate that at least some species of *Armillaria* depend almost entirely on rhizomorphs as their principal means of dispersal (Smith et al. 1992). *Ganoderma* species are not known to produce either chlamydospores or rhizomorphs. The mode of infection by these species is not known. Species of all of these genera and those of others that cause root and heart rot primarily use a root-to-root transmission in the formation of infection centers. However, basidiospores are the means by which long-distance spread of the fungus is accomplished, and this could be very effective in an ecosystem that lacks the normal competitors.

Most root- and heart-rot fungi act similarly. In the case of the attack of a tree beyond an infection center, the mycelium or rhizomorphs in the soil or debris are in close proximity to the root system. In the case of rhizomorphs, they may be attached but not causing damage (Wargo 1984). When the tree is stressed, the root is penetrated, and the mycelium grows through the root. The mycelium continues growth toward the root crown, killing roots until the complete root system is dead. Spread occurs through growth from one root system to another, causing “infection centers” that increase in size with time. Mushrooms and conks, the spore-bearing part of the life cycle, are formed in the fall and discharge spores into the air, where they are carried by wind. Although the basidiospores are not important in the localized spread of the fungus or in the formation of infection centers, they probably are the means of long-distance spread of the fungus into new areas. No conidiospore state exists in the life cycle of *Armillaria* or *Ganoderma* species, but there are indications that some *Phellinus* species may form chlamydospores in the soil.

Specific Information Relating to Risk Elements—

A. Likelihood of introduction

1. Presence with host or commodity at origin potential: *High* (*VC*) (Applicable risk criteria: c, d, e, g, h)
   Because *Armillaria, Phellinus, Ganoderma,* and other root-rot species are common worldwide and occur as cambium, root, and butt rots, any log harvested could be infected with one of these fungi. Incipient infections could easily escape detection, resulting in the log’s being processed into packing material. Because these species are excellent saprophytes, they do not need the living tree to exist, and the processing into packing materials would not destroy the fungi. Because the poorest wood is often used for packing, there is even greater likelihood that one of these species will be present.

2. Entry potential: *High* (*VC*) (Applicable risk criteria: b, c, d)
   The root- and heart-rot fungi can survive well as saprophytes. Therefore, they would easily be able to survive during harvest, milling, and transport to the United States. Given the likelihood of significant moisture availability (in holds of ships, on docks, holding areas, etc.), the conditions could well be ideal

for growth of these fungi in the wood. Additional entry potential exists because rhizomorphs and mycelium of these species could be under the bark on poorly debarked packing material.

3. Establishment potential: *Moderate* (*RC*) (Applicable risk criteria: b, c)
   Because most of the root- and heart-rot fungi do not produce conidiospores or other easily disseminated propagules and are not transmitted by insects, the likelihood of dissemination of these fungi from imported packing materials to appropriate substrates in the United States is low. However, basidiomes and basidiospores may be produced if these materials are exposed to extended or repeated periods of moisture. Also, storage of packing materials in moist areas awaiting reuse would allow development of the basidiomes and basidiospores.

4. Spread potential: *Moderate* (*MC*) (Applicable risk criteria: a, d, e, g)
   Spread of these fungi depends heavily on the effectiveness of the basidiospores in infecting an appropriate substrate or host. Because packing materials can be stored and reused or moved from the port to some other part of the United States, the potential availability of an acceptable host is increased. If the packing material is not kept sufficiently dry in storage, basidiomes could be formed, basidiospores produced, and the spread potential greatly increased.

B. Consequences of introduction

5. Economic damage potential: *Moderate* (*RC*) (Applicable risk criteria: a, b)
   These fungi could cause tree mortality by causing root-rots on stressed trees. Because of the perceived slow spread potential of these species and the usual restriction to infection centers, spread probably would be slow. The economic impact would also be slow to develop and would probably never be major. However, there is a possibility that newly introduced species of these fungi will be effective at long-distance dispersal and establishment of populations and will be able to compete well with the native populations. This will increase the damage potential of these species. This uncertainty can not be quantified.

6. Environmental damage potential: *Moderate* (*MC*) (Applicable risk criteria: d)
   The environmental damage caused by root rot species likely to be imported is low because of their assumed ability to spread at only slow rates (Smith et al. 1992). The probable restriction to infection centers will cause minor environmental damage. However, under certain conditions and in certain areas, infection centers could cause significant damage—especially in ornamental and specimen trees. A factor that is difficult to evaluate but should certainly be considered is the competition with native species and the impact on other elements of the ecosystem. In addition to the potential damage to natural forests, root and heart rots are capable of attacking horticultural crops, nursery stock, and orchards. In the Western United States, orchard crops, vineyards, and ornamentals are known to be attacked by the native species of *Armillaria* (K. Johnson, personal communication). An exotic *Armillaria* species (or other root or heart rotter) could well be more damaging.

7. Social and political considerations : *Moderate* (*MC*) (Applicable risk criteria: a)
   Increased mortality in native forests and horticultural plantings could have significant social and political impacts only if the fungus spreads rapidly. This is not expected for species of root- and heart-rot fungi.

C. Pest risk potential: **Moderate** (Likelihood of introduction = *Moderate*; Consequences of introduction = *Moderate*).

Heterobasidion Root Rot

Assessor—Harold Burdsall

Scientific Name of Pests—*Heterobasidion annosum* (Fr.) Bref. (European strains), *H. parvisporum* Niemelä & Korhonen, *H. abietinum* Niemelä & Korhonen, *H. araucariae* Buchanan, *H. insulare* (Murr.) Ryv., *H. pahangense* Corner, *H. perplexum* (Ryv.) Stalpers, *H. rutilantiforme* (Murrill) Stalpers (Basidiomycetes).

Scientific Names of Hosts—
Heterobasidion annosum (Fr.) Bref. (European strains): *Pinus* spp., *Picea* spp., *Juniperus* spp., *Larix* spp., *Pseudotsuga* spp., *Betula* spp. and other hardwoods (Bendz-Hellgren et al. 1998, Fiodorov 1998, Niemelä and Korhonen 1998) (pathogenic).
Heterobasidion parvisporum Niemelä & Korhonen: *Picea* spp. (pathogenic).
Heterobasidion abietinum Niemelä & Korhonen: *Abies* spp. (pathogenic), *Picea* spp.
Heterobasidion araucariae Buchanan: *Araucaria, Agathis, and Pinus* spp. (nonpathogenic?).
Heterobasidion insulare (Murr.) Ryv.: *Abies* spp., *Pinus* spp., *Picea* spp. (nonpathogenic?).
Heterobasidion pahangense Corner: tropical spp.
Heterobasidion perplexum (Ryv.) Stalpers: *Tsuga* spp.
Heterobasidion rutilantiforme (Murrill) Stalpers: tropical spp.?

Although the pathogenicity of several of these species has not been demonstrated, the possibility that they are weak pathogens that could have greater virulence on North American species must be considered.

Distribution—
Heterobasidion annosum (Fr.) Bref. (European strains): throughout Europe.
Heterobasidion parvisporum Niemelä & Korhonen: mostly northern Europe, also central and southern European montane *Picea* forests.
Heterobasidion abietinum Niemelä & Korhonen: mostly the Mediterranean *Abies* forests.
Heterobasidion araucariae Buchanan: in eastern Australia, New Zealand, Papua New Guinea, and the Fiji Islands.
Heterobasidion insulare (Murr.) Ryv.: eastern Asia, Himalayas, Burma, Philippines, China, Russian Far East, and Japan.
Heterobasidion pahangense Corner: Malaya.
Heterobasidion perplexum (Ryv.) Stalpers: Nepalese mountains.
Heterobasidion rutilantiforme (Murrill)Stalpers: American tropics.

The true extent of distribution of several of the species (especially the tropical ones) is not known. It is expected that they would be widespread or have equally suspect closely related species in other tropical areas.

Summary of Natural History and Basic Biology of the Pest—*Heterobasidion* species cause a root, butt, and heart rot of numerous hosts throughout Europe and the other parts of the world. They can also maintain themselves saprophytically for periods of up to 62 years in dead infested stumps (Grieg and Pratt 1976, Piri 1996). The species are reported to cause major growth reductions and mortality in areas where selective harvesting or precommercial thinning is practiced (Froelich et al. 1977) in both the Southeastern and Western United States (Schmitt et al., unpublished; Goheen and Goheen 1989). As much as 30 percent mortality in thinned *Pinus elliottii* Engelm. stands is known (Robbins 1984). In addition to the potential damage to natural forests, root and heart rots are capable of attacking horticultural crops, nursery stock, and orchards. In the Western United States, orchard crops, vineyards, and ornamentals are known to be attacked by native species of *Heterobasidion* (K. Johnson, personal communication). An exotic *Heterobasidion* species could well be more damaging. Infected trees support the fruiting of the basidiomes that are the source of basidiospore inoculum when the fungus fruits. Freshly cut stumps are infected by these propagules, are decayed, and provide inoculum for root-to-root infection of healthy trees. On the basis of the host species, the decay may be restricted to particular tissues or be dispersed throughout the lower part of the trunk. Conifer species are particularly susceptible, depending on the host genus and the species (or strain) of *Heterobasidion* involved. The species known to date are rather specific in their pathogenicity to pines (*H. annosum*), spruce (*H. parviporum*), and fir (*H. abietinum*). *H. annosum* is the exception, because it also occurs on several hardwood species. These species were merely considered as strains of *H. annosum* (Korhonen et al. 1989) until recently when more thorough study demonstrated them to be distinct (Niemelä and Korhonen 1998). For wood-inhabiting basidiomycetes, *Heterobasidion* species are unusual in that they may form an anamorph producing conidiospores that are potential inoculum. The function of the conidiospores in nature is not understood. They can be transported by water movement or insects and can be found in insect galleries. Also, small animals and birds can disseminate these conidiospores; the mode is passive: conidiospores adher to the bodies of these creatures (Brasier 1978). However, the conidiospores have been demonstrated to survive passage through the alimentary canal of several types of insects (e.g. beetles) that could be associated with wooden crates (Nuorteva and Laine 1968, Kadlec et al. 1992). Whether conidiospores are effectively wind disseminated is uncertain because they are not forcibly discharged and are usually produced underground away from most air currents. However, Hsiang et al. (1989) reported that up to half of airborne *H. annosum* spores are conidiospores, and there are numerous reports of conidiospores being found on moist wood surfaces (Kallio 1971), but others indicate that conidiospores are not common on aboveground substrates (Rishbeth 1951, Kelly and Davis 1973). These propagules are definitely effective inoculum, having been used consistently to infect stumps in research on the disease, and were shown to be effective inoculum in Sweden for the infection of seedlings (Hüppel 1970). Being passively discharged, they are probably not involved in long-distance dispersal. The vegetative stage can be found between the wood and bark of infected trees as well as in heartwood if the substrate is in the right condition. The mycelium of *Heterobasidion* may exist in wood for long periods and may then produce the *Spiniger* anamorph.

Specific Information Relating to Risk Elements—

A. Likelihood of introduction

1. Presence with host or commodity at origin potential: *High* (*VC*) (Applicable risk criteria: c, d, e, g, h)
   Heterobasidion species occur commonly in Europe on numerous conifer species from which SWPM may be made and exported worldwide. Other species are found in many other countries from which crating may be exported to the United States. Incipient decay caused by *Heterobasidion* could be easily overlooked in inspections of the logs after harvest or of the lumber being used as crating. The raw material used for crating is also problematic when such fungi are considered. Low-quality wood that is most likely to have some rot in the butt of the tree and attached bark is used for such products. It has been demonstrated that spores of some species can remain viable under bark scales for months (Shaw 1981, Korhonen 1981). These facts increase the likelihood of the fungus' being present in wood used for SWPM. Unfortunately, the tropical species are not well known, their distribution is uncertain, and their impact on arrival in another country with susceptible hosts is not known. Some are known only as saprophytes, but they may be minor pathogens having a virulence not yet determined. Most are known from collections taken from dead trees. However, all of the European *Heterobasidion* species fruit only on dead trees (Korhonen and Stenlid 1998), and they are well known pathogens.

2. Entry potential: *High* (*VC*) (Applicable risk criteria: b, c, d)
   Being exceedingly capable of living saprophytically, *Heterobasidion* species are well adapted to survive transport successfully in untreated processed wood under moist conditions, including high humidity. Incipient decay would be difficult to recognize in the logs intended for crating and in the processed (sawed) lumber used for constructing crates or pallets. Intact bark would make the detection of the fungi even more difficult while making their survival more likely because of mycelium under the bark and spores that have been shown to be capable of remaining viable under bark scales for months (Shaw 1981, Korhonen 1981).

3. Establishment potential: *High* (V*C*) (Applicable risk criteria: b, c, f)

Heterobasidion species normally infest an intermediate substrate (especially freshly cut stumps) as the normal means of invading a new area, although injured roots may be attacked and infected directly (Zycha and Klieforth 1971, Rosnev 1982, Alcubilla et al. 1990) by basidiospores. For this to occur, the fungus must produce basidiomes on the imported wood. This requires sufficiently moist conditions for the basidiomes to develop and the basidiospores to be produced in an area with susceptible host material.

Also, *Heterobasidion* species produce conidiospores (the *Spiniger* anamorph). These conidiospores are produced in substantial quantity and are potential inoculum for establishing the fungus in a new environment. Their effectiveness in long-range dispersal in nature is not known, nor is the ability of the conidiospores to infest dead woody material. However, small animals, birds, and insects can disseminate the conidiospores. The mode is normally passive: conidiospores adher to the bodies of these creatures (Brasier 1978), although conidiospores have been demonstrated to survive passage through the alimentary canal of several types of insects (e.g. beetles) that could be associated with wooden crates (Nuorteva and Laine 1968, Kadlec et al. 1992). Under damp conditions, there is a possibility that conidiospores will be produced on crating and carried by any number of means (running or splashing water, insects, rodents) to a nearby substrate for further inoculum buildup. If insects transported within the wood material emerged and conidiospores were picked up on body parts, dissemination to susceptible hosts is possible.

4. Spread potential: *High* (*MC*) (Applicable risk criteria: a, c, d, e, g)
   Heterobasidion species are well adapted for dissemination of basidiospores. The basidiospores are effective infection agents—especially in areas where fresh stumps are available. However, to produce basidiospores, the fungus must produce the basidiome. Conidiospores may also be infesting propagules. However, stumps of freshly cut trees are the preferred substrate for both spore types. Long-distance transport of crates and pallets over land can easily allow for the widespread distribution of these spores into habitats that can be affected by *Heterobasidion* species. Because a freshly cut stump is, by far, the most likely substrate, the likelihood of spread is reduced. Within-stand spread of *Heterobasidion* species is normally slow because of the predominant spread by root-to-root transmission of the fungus. Such spread is indicated to be less than 1 m/yr regardless of host species (Redfern 1984, Chavez et al. 1980, Swedjemark and Stenlid 1993, Morrison and Redfern 1994). However, the basidiospores have been trapped as far as 300 km from any possible source (Rishbeth 1959, Kallio 1970). This may allow for a much faster spread than would be normally considered. It must also be recognized that the spores of both types can be transmitted, though passively, by insects and small mammals. The spread potential of the tropical and poorly studied species is impossible to predict because so little is known of their biology. However, once established, the fungus could spread with the same facility as in its native country—and possibly faster because of the potentially greater susceptibility of the host species available.

B. Consequences of introduction

5. Economic damage potential: *Moderate* (*MC*) (Applicable risk criteria: a, b, c)
   The potential impact of introducing European or other species of *Heterobasidion* inon the conifer forests of the United States is considerable. In Germany and Austria, losses of 130 million DM/yr have been encountered (Dimitri and Tomiczek 1998), whereas a 20 percent decrease in volume was evident in 60-year-old heavily infested plots in France (Delatour 1997). The economic impact of European *Heterobasidion* species is significant where they are native. One can expect the impact to be increased if these fungi are associated with host species with which they have not evolved. They may be expected to impact forests of *Pinus, Abies, Picea, Betula* and possibly other hardwoods because the European strain of *H. annosum* was originally described from *Betula* and is known to affect several hardwood species (Niemelä and Korhonen 1998, Bendz-Hellgren et al. 1998). Because these species spread primarily by root-to-root infection, their spread and thus their economic impact would be slower to develop than those of vectored or airborne pathogens. The need for freshly cut stumps as a substrate to incite infection in

distant areas will also limit the potential damage. However, once the fungus is introduced, the production of basidiospores will provide the means for long-range spread, for basidiospores have been found up to 300 km from the nearest possible source (Rishbeth 1959). Though vectoring of both spore states is passive, this method of dissemination and spread of the pathogen must not be minimized. The damage potential of less-well-known *Heterobasidion* species, especially those from the tropics, is unknown because little or nothing is known of their biology.

In addition to the potential damage to natural forests, root and heart rots are capable of attacking horticultural crops, nursery stock, and orchards. Introduction of a new root- or heart-rot species to such crops has the potential to incite significant damage. Solid wood packing materials are a major means by which supplies (fertilizer, mulch, chemicals) reach growing areas for such crops and would be a potential means by which root- and heart-rot fungi could be introduced.

6. Environmental damage potential: *Moderate* (*MC*) (Applicable risk criteria: d)
   The introduction of the exotic species of *Heterobasidion* in the United States could cause forest losses additional to the native *Heterobasidion* species. It is possible that exotic species would create problems in the hardwood forests, especially to *Betula* spp., which to this point has been untouched by *Heterobasidion* root rot. The impact on native hardwoods is difficult to predict, but the pathogenicity of the European species to hardwoods (Niemelä and Korhonen 1998, Bendz-Hellgren et al. 1998) indicates that exotic species have a detrimental potential.

7. Social and political considerations: *Moderate* (*MC*) (Applicable risk criteria: a)
   Increased losses to the forest ecosystem will cause concern on the part of the environmental community. The extent of this dissatisfaction is impossible to predict.

C. Pest risk potential: **High** (Likelihood of introduction = *High*, Consequences of introduction = *Moderate*).

Brown Root Rot

Assessor—Charles S. Hodges

Scientific Name of Pest—*Phellinus noxius* (Corner) G.H. Cunn. [= *Fomes noxius* Corner] (Basidiomycota, Hymenochaetaceae).

Scientific Names of Hosts—More than 50 genera of tropical trees have been reported as hosts to *P. noxius*, including conifers such as *Pinus* spp. and *Araucaria spp.*; commercial forest plantation hardwoods such as *Eucalyptus* spp., *Swietenia* spp., and *Acacia* spp.; *Heavea brasiliensis* (Willd. ex Adr. Juss.) Mull. Arg. (rubber); *Elaeis guineensis* Jacq. (oil palm); *Theobroma cacao* L. (cocoa); *Artocarpus altilis* (Parkins) Fosb.(breadfruit); and *Camellia sinensis* (L.) Kuntze (tea). The fungus also occurs as a common component of many native tropical forests.

Distribution—Throughout east and central Africa; Asia, including India, Indonesia, Malaysia, Pakistan, Philippines, and Taiwan; Australia (Queensland); the Pacific Islands, including American Samoa, Guam and the Northern Mariana Islands, Costa Rica, Cuba and Puerto Rico. The report from Puerto Rico is suspect. A recent review of the fungal data bases on that island by Lodge (personal communication) did not contain any records of *P. noxius*. The fungus has not been found in the continental United States or Hawaii.

Summary of Natural History and Basic Biology of the Pest—*Phellinus noxius* causes a root rot of many tree species in the Pacific Islands, Africa, and Asia. Although it occurs in native forests, it is most damaging in plantations of forest trees and important fruit and commodity crops such as breadfruit, rubber, cocoa, and oil palm (Pegler and Waterston 1968). On the island of Saipan, the fungus caused serious damage to *Delonix regia* (Bojer ex Hook.) Raf., an important amenity tree on the island (Hodges and Tenorio 1984). New infection centers may be initiated when tree plantations are established on cleared native forest in which the fungus is present. Infection occurs when roots of the planted trees make contact with stumps or other woody debris that contain the fungus. Further spread from the initial infection centers is through root contact. Airborne basidiospores produced in fruiting bodies on dead or dying trees or stumps can also initiate new infections on freshly cut stump surfaces or through wounds on living trees with subsequent spread by root contact. In culture, the fungus produces an asexual spore state (Chang 1996), but such spores have not been observed in the field; moreover, it is not known what role they may play in the spread of the fungus.

The fungus often produces a characteristic brownish mycelial sheath on the bark surface of infected trees (Thrower 1965, Hodges and Tenorio 1984). On large trees, this sheath may extend for 2 m or more above the root collar. Mycelium of the fungus grows radially into the tree from the sheath and may reach the heartwood of large trees (T.T. Chang, personal communication). The fungus can survive for up to 2 years in infected wood placed in the soil (Chang 1996).

Recent work in Malaysia indicates that *P. noxius* is associated with a serious heart-rot problem in young plantations of *Acacia mangium* (Lee and Zakaria 1993). In contrast to other hosts in which the fungus decays the roots and results in death of the tree, on *A. mangium* it causes a typical heart rot that may extend for several meters. Infection apparently occurs by airborne spores through pruning wounds or broken branches. On this host, no external mycelial sheath is present, and tree growth is not affected. It is not known whether a different strain of the fungus is involved or whether the host response is different in this particular tree species. There have not been previous reports of physiological specialization in this fungus. Chang (1995) reported that in cross-inoculation studies with isolates of the fungus from 12 hosts, all hosts were infected by all isolates, indicating that the fungus did not exhibit host specificity.

Specific Information Relating to Risk Elements—

A. Liklelihood of introduction

1. Presence with host or commodity at origin potential: *High* (*VC*) (Applicable risk criteria: c, d, e, g, h)
   Phellinus noxius is widely distributed in the tropics on a large number of tree species, many of which could be used for SWPM.

2. Entry potential: *High* (*MC*) (Applicable risk criteria: b, c, d)
   Phellinus noxius can survive in wood over a period of 2 or more years (Chang 1996). Although there are no specific reports that basidiocarps can be produced on sawed infected wood, the fungus is able to produce basidiocarps on stumps and other woody debris, and Chang (1995) has produced fertile basidiocarps on inoculated sawdust. If basidiospores, conidia, or both were produced on infected wood used for packing material, chances of infection of nearby susceptible hosts would be good. *Phellinus noxius* is present in many isolated island groups in the Pacific Basin where the fungus has most likely been introduced in some manner. On the island of Rota in the Northern Marianas Islands, the largest, and presumably the oldest, focus of infection was found adjacent to the airport (Hodges and Tenorio 1984). Although circumstantial, this evidence points to the possibility of introduction of the fungus through imported woody material infected by the fungus.

3. Establishment potential: *High* (*RC*) (Applicable risk criteria: b, c, f)
   Should basidiospores, conidia, or both be produced on infected packing material, the likelihood of establishment would be high. Wounds on susceptible tree species, especially ornamentals, at or near the port of entry could easily be infected by airborne spores of the fungus.

4. Spread potential: *Moderate* (*VC*) (Applicable risk criteria: a, c, d, g)
   Once basidiocarps are produced in the initial colonization center, the likelihood of spread to surrounding areas by airborne basidiospores is high. Susceptible trees could be infected directly through basal wounds or indirectly by root contact with stumps that were infected through the cut surface.

B. Consequences of introduction

5. Economic damage potential: *Moderate* (*RC*) (Applicable risk criteria: a, b, c)
   Although the fungus has the potential to cause serious damage in commercial fruit and forestry plantations, especially in Hawaii and Puerto Rico, this damage can be mitigated to some degree through control strategies already worked out for plantation crops such as rubber and cocoa. Potential damage in the subtropical region of the continental United States is more problematic, but the fungus is known to cause damage in similar climates.

6. Environmental damage potential: *High* (*RC*) (Applicable risk criteria: a, b, c, d)
   Introduction into the native forests on Hawaii and Puerto Rico could result in serious environmental damage to these ecosystems—not only to the dominant tree species but to associated woody species as well—some of which are threatened and endangered. Damage may also be expected in amenity trees and home fruit trees.

7. Social and political considerations: *High* (*RC*) (Applicable risk criteria: a, b, c)
   Potential damage to native ecosystems, landscape esthetics, and home fruit trees could have great social and political repercussions. This is especially true in tropical areas where fruits such as mango and breadfruit, ornamental trees such as *Delonix regia*, and native forest ecosystems make up a large part of the tropical mystique so appealing to tourists.

C. Pest risk potential: **High** (Likelihood of introduction = *Moderate*; Consequences of introduction = *High*).

Stains and Wilts

Assessor—Eugene B. Smalley

Scientific Names of Pests—Pests covere– in this topic constitute a very large group of saprophytic and pathogenic fungi in the Ascomycetes orders Ophiostomatales *(Ophiostoma* and *Ceratocystis*) and Microascales (*Microascus* and *Petriella*) (table D–4). Anamorphs associated with *Ophiostoma* spp. include species of *Sporothrix*, *Leptographium*, *Hyalorhinocladiella*, *Pesotum*, *Graphium*, *Acremonium*, and probably others (de Hoog 1993, Nag Raj and Kendrick 1993, Seifert and Okada 1993, Wingfield 1993). *Graphium*-like wood stainers are anamorphs of *Petriella* and *Microascus* (Seifert and Okada 1993). Anamorphs associated with *Ceratocystis* spp. are mainly species of *Chalara* (Nag Raj and Kendrick 1993). With the aid of modern DNA molecular tools, the nomenclature and taxonomy of many of the groups and species within the Ophiostomatales are currently under intensive study, and a more accurate understanding of relationships within this large group of wilt and stain fungi is emerging (Harrington et al. 1996, Harrington et al. 1998; T. Harrington 1999, personal communication).

Scientific Names of Hosts—Numerous coniferous and deciduous tree species as well as various crop plants in both temperate and tropical regions of the world (table D–4).

Distribution—Worldwide. Molecular studies to define continents of origin of this diverse group of fungi have been conducted, but in most cases these fungi remain to be studied (Brasier and Kirk 1993, Hausner et al. 1993, Strydom et al. 1997, Witthuhn et al. 1998).

Summary of Natural History and Basic Biology of Pests—A large majority of the more than 120 plus described species of Ophiostomatoid fungi have intimate associations with arthropods and insects, especially bark beetles (Scolytidae) (i.e., *Ophiostoma*) and nitidulids (Nitidulidae) (i.e., *Ceratocystis*) (Harrington 1993, Mallock and Blackwell 1993). In fact, one of the taxonomically distinctive features of most of the species in the genus *Ophiostoma* is their close association with bark beetles (Wingfield et al. 1993). Some of the species have been shown to have a more highly evolved relationship with their bark beetle vectors as specific mycangial fungi (Harrington and Zambino 1990, Six and Paine 1997). On the other hand, with few exceptions, species of *Ceratocystis* do not have bark beetle associations but rather are associated with species of nitidulids (Nitidulidae), mites, and other insect groups that are attracted by strongly aromatic or fruitlike odors produced by these species of *Ceratocystis* (Mallock and Blackwell 1993).

A large proportion of the described *Ophiostoma* species are associated with coniferous forests and especially the conifer-associated insects of Western North America, including Mexico and Canada (Upadhyay 1981, Wingfield et al. 1993, Wood 1982; and others). *Ophiostoma conicolum* Marmolejo & Butin and *O. abietinum* Marmolejo & Butin have been reported from Mexico (Tkacz et al. 1998). The world's conifer-inhabiting bark beetles and their associated fungi appear to be concentrated in North America. On the other hand, the major gene center for the northern (Palearctic) hardwood scolytids spans the Eurasian continents. The 47 major palearctic *Scolytus* bark beetle species are described in a little seen monograph by the Polish scientist Michalski (1973). The Ophiostomatoid fungi associated with this large group of hardwood bark beetles have been given very little attention by scientists.

Most *Ophiostoma* species are saprophytes or weakly pathogenic fungi in their native ecosystems (Harrington 1993, Upadhyay 1981, Wingfield et al. 1993). Some species are major wood-staining fungi of conifers (Anselmi and Invernizzi 1992, Farrell et al. 1997, Gibbs 1993, Harrington 1993, Krokene and Solheim 1997, 1998a, b; Solheim and Safranyik 1997, Solheim and Krokene 1998, Upadhyay 1981), whereas a few, such as *Ophiostoma ulmi* (Buisman) Nannf. (sensu lato), are major pathogens and have produced worldwide devastating epidemics in elms (Brasier 1991, Gibbs 1978a). The continued discovery of new races and forms of the Dutch elm fungus (i.e., *Ophiostoma novo-ulmi* and *O. himal-ulmi* Brasier & Mehrotra) in North America, Europe, and Asia indicates a real and continued threat of introducing new strains or races of this important pathogen (Brasier 1991, Brasier and

Table D–4. Species of *Ceratocystis* and *Ophiostoma*[1]

Species	Location[2]	Plant host	Insect associates[3]
Ceratocystis species			
C. acericola	North America	Hardwoods	
C. adiposa	Worldwide	Tropicals	
C. autographa	Europe	Conifers	Bark beetles
C. coerulescens	Worldwide	Conifers	Bark beetles
C. douglasii	North America	Conifers	
C. eucalypti	Australia	Hardwoods	
C. fagacearum	North America	Hardwoods	Nitidulidae
C. fimbriata	Worldwide	Hardwoods, tropicals	Ambrosia beetles
C. hyalothecium	North America	Conifers	
C. laricicola	Eurasia	Conifers	Bark beetles
C. magnifica	North America	Conifers	
C. moniliformis	Worldwide	Tropicals	
C. polonica	Eurasia	Conifers	Bark beetles
C. paradoxa	Worldwide	Tropicals	
C. radicicola	North America	Palms	
C. stenospora	North America	Hardwoods	
C. virescens	North America	Hardwoods	
Ophiostoma species			
O. abietinum	North America	Conifers	Bark beetles
O. abiocarpum	North America	Conifers	Bark beetles
O. adjuncti	North America	Conifers	Bark beetles
O. aenigmaticum	Japan	Conifers	
O. aequivaginata	North America	Conifers	
O. americanum	North America	Conifers	
O. ainoae	Eurasia	Conifers	Bark beetles
O. allantospora	North America	Conifers	Bark beetles
O. angusticolla	North America	Conifers	
O. araucaria	South America	*Araucaria*	
O. arborea	North America	Conifers	
O. aureum	North America	Conifers	
O. bacillosporum	Europe	Hardwoods	Ambrosia beetles
O. bicolor	North America, Japan	Conifers	Bark beetles
O. brevicolla	North America	Hardwoods	Ambrosia beetles
O. brunneo-ciliatum	Europe	Conifers	Bark beetles
O. brunneocrinita	North America	Conifers	
O. cainii	North America	Conifers	
O. californica	North America	Conifers	
O. canum	Europe, North America	Conifers, hardwoods	Bark beetles

Table D–4 Continued. Species of *Ceratocystis* and *Ophiostoma*[1]

Species	Location[2]	Plant host	Insect associates[3]
O. clavigerum	North America	Conifers	Bark beetles
O. columnaris	North America	Conifers	
O. conicolum	North America	Conifers	
O. coronata	North America	Conifers	
O. crassivaginatum	North America	Hardwoods, conifers	
O. cucullatum	Eurasia	Conifers	Bark beetles
O. davidsonii	North America	Conifers	
O. deltoideospora	North America	Conifers	
O. denticulata	North America	Conifers	Ambrosia beetles
O. distortum	Eurasia, North America	Conifers	Ambrosia beetles
O. dryocoetidis	North America	Conifers	Bark beetles
O. epigloeum	North America	Basidiomycetes	
O. europhioides	North America, Japan	Conifers	Bark beetles
O. flexuosum	Europe	Conifers	
O. francke-grosmanniae	Europe	Hardwoods	Bark beetles
O. grande	Europe	Hardwoods	
O. grandiocarpum	Europe	Hardwoods	
O. grandifoliae	North America	Hardwoods	
O. himal-ulmi	Asia	Hardwoods (elm)	Bark beetles
O. huntii	North America	Conifers	Bark beetles
O. introcitrina	North America	Hardwoods	
O. ips	Worldwide	Conifers	Bark beetles
O. japonicum	Asia	Conifers	Bark beetles
O. leptographioides	North America	Hardwoods	
O. leucocarpa	North America	Conifers	Bark beetles
O. microspora	North America	Hardwoods	
O. megalobrunneum	North America	Hardwoods	
O. minus	Eurasia, North America	Conifers	Bark beetles
O. montia	North America	Conifers	Bark beetles
O. multiannulatum	North America	Conifers	
O. narcissi	Worldwide ?	Bulbs	
O. nigrocarpum	North America	Conifers	Bark beetles
O. nigrum	North America	Conifers	Ambrosia beetles
O. nothofagi	South America	Hardwoods	
O. novo-ulmi	Eurasia, North America	Hardwoods (elm)	Bark beetles
O. novae-zelandiae	New Zealand		
O. obscura	North America	Conifers	
O. olivaceapinii	North America	Conifers	Bark beetles
O. olivaceum	North America	Conifers	
O. penicillatum	Eurasia	Conifers	Bark beetles
O. perparvispora	North America	Hardwoods	
O. piceae	Worldwide	Hardwoods, conifers	Bark beetles
O. piceaperdum	North America	Conifers	Bark beetles

Table D–4 Continued. Species of *Ceratocystis* and *Ophiostoma*[1]

Species	Location[2]	Plant host	Insect associates[3]
O. piliferum	Worldwide	Hardwoods, conifers	Bark beetles
O. pluriannulata	North America	Hardwoods	
O. polyporicola		Basidiomycetes	
O. populicola	North America	Hardwoods	
O. populinum	North America	Hardwoods	
O. pseudominor	North America	Conifers	
O. robustum	North America	Conifers	
O. roraimense			
O. rostrocoronatum	North America	Hardwoods	
O. rostrocylindricum	North America	Conifers	
O. sagmatospora	North America	Conifers	
O. serpens	North America	Hardwoods	
O. seticolle	North America	Conifers	Ambrosia beetles
O. sparsum	North America	Conifers	
O. stenoceras	Worldwide	Hardwoods, conifers	Bark beetles
O. subanulatum	North America	Conifers	
O. tenella	North America	Hardwoods, conifers	
O. tetropii	Europe	Conifers	Bark beetles
O. torticiliata	North America	Hardwoods	
O. tremulo-aurea	North America	Hardwoods	
O. triangulosporum	South America	*Araucaria*	
O. trinacriforme	North America	Conifers	
O. tubicollis	North America	Conifers	
O. ulmi	Eurasia, North America	Hardwoods (elm)	Bark beetles
O. valdivianum	South America	Hardwood	
O. wageneri	North America	Conifers	Bark beetles

1/ List updated from Seifert et al. (1993), USDA Agricultural Research Service fungal data bases (1 April 1999) on the Internet, and from Upadhyay (1981). The species in the Ophiostomatales are currently undergoing extensive study and revision. Numerous changes in the currently accepted species (above) can be expected.

2/ North America includes only the United States and Canada (not Mexico or Central America).

3/ Many, if not all, of the species in the Ophiostomatales have insect associations, but these relationships in most species have not been studied. Reports of isolation or detection only on hardwood or conifer host plants do not exclude the existence of highly evolved insect vector relations.

Mehrotra 1995). The origin of the Dutch elm disease pandemic that began in Europe after World War I is uncertain and may or may not have been caused by *O. himal-ulmi* or its ancestors (Pipe et al. 1997). In all probability, related forms of this fungus lie undiscovered among the subtropical and tropical species of elms (e.g., *Ulmus pumila* L., *U. chumlia* Melville and Heybroek, *U. wallichiana* Planch., *U. villosa* Brandis & Gamble,, *U. changii* Cheng, *U. bergmanniana* Schneid., *U. microcarpa* L.K. Fu,, *U. lanceifoila* Roxb. and Wall, *U. tonkinensis* Gagnep.) that still exist in Asia in the southern foothills of the Himalayan mountain range and along the upper reaches of the rivers whose waters are derived from the Himalayan mountains (e.g., Indus, Ganges, Salween, Irrawadi, and the Mekong) (Fu and Xin 2000, Melville and Heybroek 1971, Smitinand 1980).

Scientists at the Institute of Forestry, Chinese Academy of Forestry, Beijing, investigated the possible occurrence of Dutch elm disease associated with declining and dying elm plantations in China and associated Chinese bark beetles (Liu 1988, Smalley 1984). They failed to discover the causal fungus of Dutch elm disease in these surveys (Brasier 1990, Smalley 1984). However, they reported on the virulence of the associated stain fungi *Graphium penicilloides* Corda and *G. putredinis* (Corda) Hughes from these dying elms. These species of *Graphium* are morphologically similar to the *Graphium* spp. isolated commonly from elms invaded by bark beetles in North America and from various pine bark beetles in the Southern United States having *Petriella* (Microascales) teleomorphs (Smalley 1990, unpublished research). In China, *G. penicilloides* and *G. putredinis* were commonly associated with dying elms attacked by various Chinese species of bark beetles (e.g., *Scolytus scheryrewi* Semenov, *S. semenovi* Spessivtseff, and *S. butovitschi* Stark (Liu 1988, Yang et al. 1988; Yin 1987, personal communication).

Numerous *Ophiostoma* spp. along with their bark beetle associates have been reported from Western Russia (USDA Forest Service 1991). A search of numerous western literature data bases available for research published since the appearance of "*Ceratocystis* and *Ophiostoma*: Taxonomy, Ecology, and Pathogenicity" (Wingfield et al. 1993) turned up few Asian citations for the key words *Ophiostoma* or *Ceratocystis*. The probability is great, however, that *Ophiostoma* species from eastern Russia and northeast China will be different from those known from Western North America. Among recent Asian reports of conifer-associated ophiostomatoid fungi, nine species, including one new species, were identified in Yezo spruce [*Picea jezoensis* (Sieb. and Zucc.) Carr.] trees infested with *Ips typographus* L. f. *japonicus* Niijima in Hokkaido, Japan, including *Ceratocystiopsis minuta* (Siemaszko) Upadhyay and Kendrick, *Ceratocystis polonica* (Siemaszko) Moreau, *Ophiostoma ainoae* Solheim, *O. bicolor* Davidson and Wells, *O. cucullatum* Solheim, *O. europhioides* (Wright and Cain) Solheim, *O. penicillatum* (Grosm.) Siemaszko, *O. piceae* (Munch) Syd. and P. Sydow, and a new species *O. japonicum* (Yamaoka et al. 1997). On the basis of frequency of occurrence, *O. ainoae*, *O. bicolor*, *O. penicillatum*, and *O. piceae* were regarded as dominant associates of *I. typographus japonicus*, and *C. minuta*, *C. polonica*, *O. europhinoides*, and *O. japonicum* were subdominant. The species of ophiostomatoid fungi associated with *I. typographus japonicus* in Japan are almost identical to those associated with *I. typographus* infesting Norway spruce (*Picea abies* (L.) Karst.) in Europe (Yamaoka et al. 1997).

The major Chinese bark beetles, their respective hosts, and locations of occurrence are listed in table D–5 (Yin 1987, personal communication). *Tomicus pinipera* L. was reported to be epidemic in the Yunnan Province of China on *Pinus yunnanensis* Franch. between 1980 and 1989, and in 1987 more than 48,000 ha of pine forests were being decimated. Fungi associated with this outbreak have not been investigated (Yin 1989, personal communication).

In marked contrast to fungal species in the genus *Ophiostoma*, all of the described species in the genus *Ceratocystis* are virulent plant pathogens worldwide (Kile 1993) (table D–4). Recent studies on the relationships among the species in the *Ceratocystis coerulescens* complex confirm the hazards associated with importation of unmanufactured wood of *Abies* and *Picea* spp. from Europe (*C. polonicum*, *C. coerulescens, C. laricicola* Redfern and Minter, and their bark beetle vectors). The newly discovered species *Ceratocystis eucalypti* Yuan and Kile (Australia) and the related anamorphs *Chalara neocaledoniae* Kiffer and Delon (New Caledonia) and *Chalara australis* Walker and Kile (Australia) may be of particular concern for the United States, where various *Eucalyptus* species have long been grown in the subtropical regions as timber and ornamental trees (Kile and Walker 1987, Kile et al. 1996, Witthuhn et al. 1998). *Ceratocystis eucalypti* and the various *Ceratocystis* members of the

Table D–5. Host and locality of selected Chinese bark and ambrosia beetles[1]

Bark beetle species	Tree hosts	China locations
Scolytus		
S. schevyrewi	*Salix, Ulmus*	Northeast, Northwest
S. seulemsis	*Pinus, Ulmus*	North of the Yellow River
S. semenova	*Ulmus*	Northeast, Northwest
S. butovitschi	*Ulmus*	North of the Yellow River
S. sinopiceus	*Picea*	Northwest, Southwest
S. rugulosus	*Prunus*	All of China except Xinjiang
S. japonicus	*Pyrus, Malus, Prunus*	All of China
Hylurgops		
H. major	*Pinus*	Southwest
Dendroctonus		
D. micans	*Picea, Pinus*	Northwest, Northeast
D. armandi	*Pinus armandi*	Qinling Mountains
Phloeosinus		
P. aubei	*Biota*	All
P. sinensis	*Cunninghamia*	Along and south of Yellow River
Sphaerotrypes		
S. coimbatprensis	*Juglans, Pterocarya*	Hebei Province
Polygraphus		
P. polygraphus	*Picea, Pinus*	Northwest
Cryphalus		
C. tabulaeformis	*Pinus*	Along the Yellow River
Dryocoetes		
D. hectographus	*Pinus, Larix*	Heilongjiang Province
Pityogenes		
P. charcographus	*Piceae, Pinus, Larix*	All
Ips		
I. acuminatus	*Pinus*	All
I. typographus	*Picea, Pinus, Larix*	Northeast, Northwest
I. subelongatus	*Larix*	Northeast
I. nitus	*Abies, Picea, Pinus*	Northeast, Northwest
I. sexdentatus	*Picea, Pinus*	All
Tomicus		
T. piniperda	*Pinus*	All
Xyleborus		
X. dispar	Conifers, hardwoods	Northeast
X. rubricollis	Hardwoods	Northeast

[1/] Yin 1987, 1989, personal communication.

coerulescens complex are aggressive plant pathogens. *Ceratocystis fimbriata* Ellis & Halsted is distributed worldwide and comprises several forms, subspecies, or Clades (e.g., North American Clade, South American Clade, etc.) (Kile 1993). DNA "fingerprinting" studies of this complex group of major pathogens are currently under way (T. Harrington 1999, personal communication; Witthuhn et al. 1999). For example, on the basis of DNA studies of the sycamore (*Platanus* spp.) form of *C. fimbriata* can be considered to be native to the Southeastern United States and has spread to California, Italy, and elsewhere. The *Eucalyptus* form found in Brazil, on the other hand, belongs to the Latin American Clade. The Latin American Clade can be considered to be a major hazard because of its ability to sporulate on the cut surfaces of wood (T. Harrington 1999, personal communication). More detail on the canker stain diseases caused by *C. fimbriata* is given in the section entitled "Canker Stain" written by Charles S. Hodges, found elsewhere in appendix D.

Specific Information Relating to Risk Elements

A. Likelihood of introduction

1. Presence with host or commodity at origin potential: *High* (*VC*) (Applicable risk criteria: a, b, c, d, e, f, g, h)
   Owing to the widespread occurrence of numerous species of *Ophiostoma* and *Ceratocystis*, there is an extremely high likelihood that fungi in these genera and their associated bark beetles or other arthropod vectors will be present on untreated or insufficiently treated imports of conifer or hardwood articles, or SWPM. Detection or interception of these relatively invisible Ophiostomatoid fungal pests on or inhabiting such materials is beyond the general sensitivity of regulatory inspection systems.

2. Entry potential: *High* (*VC*) (Applicable risk criteria: b, c, d)
   In sampling the fungal flora in the facilities of a large chocolate and fudge manufacturer in Wisconsin it was found that, along with various common airborne *Penicillium* and *Aspergillus* species, *Ophiostoma piceae* sensu lato was a common component detected in air samples from the factory. Isolates from the building produced both the *Pesotum* anamorph as well as the *Ophiostoma* teleomorph in culture. Contamination was traced to wooden pallets used for handling raw materials needed in the manufacturing process (Smalley and Caldwell 1994). Although the appearance of *O. piceae*, which is known to occur worldwide, is not a major quarantine concern, detection of this species along with *O. piliferum* and other members of the *piliferum* group demonstrates the ability of this group of fungi to be transported by this pathway.

   Untreated wood can be expected to contain fungal contaminants or "riders," and these will not usually be obvious to the unaided eye. Thus, regulatory plant protection officers will very likely not detect most of these fungi. Statistics regarding quarantine interceptions will consequently not reflect their presence. Most of the fungi in the genus *Ophiostoma* will survive in wood for more than a year with favorable temperatures and moisture regimes. They may even thrive under conditions that prevail during transport of SWPM. The likelihood of spores being produced in or on untreated colonized wood surfaces once they have been delivered to ports is also high (Smalley and Caldwell 1994.) Many of the more pathogenic *Ceratocystis* species, however, are not very long-lived in low-temperature storage in pure culture or on the cut surfaces of overwintered logs. This characteristic suggests that these fungi will not survive for extended periods on dry cut lumber or other wood products. A new, undescribed species of C*eratocystis* (tentatively *C. caryae*) from hickory and associated with the hickory bark beetle (*Scolytus quadrispinosus* Say) has been demonstrated to die after only a few months on the surfaces and ends of cut logs exposed to the elements. Even apparently living ascospore masses from hickory logs did not yield pure cultures (Smalley 1994). In this case, parasitism of perithecia and ascospore masses by species of *Gliocladium* spp. (now called *Clonostachys* [Schroers et al. 1999]) was common.

3. Establishment potential: *High* (*VC*) (Applicable risk criteria: a, b, c, d, e, f)

Under conditions of transport, substantial inoculum in the form of conidiospores or ascospores can be expected to be present upon arrival at the ports of entry. The likelihood of these organisms' coming into contact with suitable hosts in some cases may be high given the presence of the appropriate vectors near the ports of entry or cargo destinations.

4. Spread potential: *High* (*MC*) (Applicable risk criteria: a, b, c, d, e, f, h)
   Many of the *Ophiostoma* spp. are not highly host or vector specific, and environmental conditions may often be present and conducive to the spread of these fungi. Potential vectors native to the United States (e.g., bark beetles in genera such as *Dendroctonus, Ips*, etc.) may in some instances be efficient at spreading these fungi through contact with infected hosts or imported natural vectors. The native elm bark beetle, *Hylurgopinus rufipes* (Eichhoff), is a good example of a North American insect that became a new and effective vector of Dutch elm disease after the pathogen was introduced (Sinclair et al. 1987). Most species of *Ceratocystis* produce strong aromatic colony odors, which might easily attract native insects such as nitidulids or others that are drawn to strong fruity smells. Thus, in many instances, the spread potential for these Ophiostomatoids can be considered high.

B. Consequences of introduction

5. Economic damage potential: *High* (*MC*) (Applicable risk criteria: a, b, c, d, e)
   The introduction of Dutch elm disease caused by *Ophiostoma ulmi* sensu lato into North America illustrates the ability of at least one species in the Ophiostomatales to colonize highly susceptible hosts, utilize native bark beetles as efficient vectors, and cause high economic losses (Sinclair et al. 1987). In spite of observations concerning the occasional poor survival of many species of *Ceratocystis* outside their natural biosphere (e.g., host–parasite existence), the extreme virulence and pandemic-producing potential of the Ophiostomatales indicate that economic damage potential can be high in the event of introduction.

6. Environmental damage potential: *High* (*MC*) (Applicable risk criteria: a, d, e, f)
   Clearly the introduction of new tree-killing strains or species of Ophiostomatoid fungi into areas of North America, where the host species may be susceptible, has a high potential to result in severe environmental damage. Loss of trees in ornamental plantings or in areas of noncommercial conifers, such as in wilderness areas, could cause considerable environmental impact.

7. Social and political considerations: *Moderate to High (MC)* (Applicable risk criteria: a, c, d)
   An accidental introduction of another blue stain fungus into the United States is not likely to cause increased social or political impacts beyond those already caused by native species. However, mortality in native conifer stands associated with new tree-killing *Ophiostoma* or *Ceratocystis* species and their natural or new insect vectors could be disastrous and justify a rating for perceived damage as moderate to high, depending upon the situation. Similarly, the introduction of a pathogen with tree-killing abilities similar to *Ophiostoma ulmi* (Buisman) Nannf. (sensu lato) into the urban tree environment would have major social impacts.

C. Pest risk potential: **High** (Likelihood of introduction = *High*; Consequences of introduction = *High*).

Canker Stain

Assessor—Charles S. Hodges

Scientific Names of Pest—*Ceratocystis fimbriata* Ellis & Halstead [=*Sphaeronaema fimbriatum* (Ellis & Halstead) Sacc., *Ceratostomella fimbriata* (Ellis & Halstead) Elliot, *Ophiostoma fimbriatum* (Ellis & Halstead) Nannf., *Endoconidiophora fimbriata* (Ellis & Halstead) Davidson, *Rostrella coffeae* Zimmerman, *Endoconidiophora variospora* Davidson, *Ceratocystis variospora* (Davidson) Moreau, *Ophiostoma variosporum* (Davidson) von Arx]. Anamorph = *Chalara*. A pathogenic form of the fungus, *Ceratocystis fimbriata* f. sp. *platani* Walter, that primarily occurs on *Platanus* spp. has also been described. (Ascomycota, Ophiostomataceae).

Scientific Names of Hosts—In temperate areas of North America and Europe the fungus may cause serious damage to forest and shade trees such as *Populus* spp. and *Platanus* spp. and to fruit trees such as *Prunus amygdalus* Batsch (almond) and *Prunus domestica* L. (prune). Among nontree hosts the most important is *Ipomea batatas* (L.) Lam. (sweet potato). In tropical areas this fungus is an important pathogen on *Hevea brasiliensis* (Willd. ex Adr. Juss.) Mull. Arg. (rubber), *Coffea* spp. (coffee), *Theobroma cacao* L. (cocoa), *Mangifera indica* L. (mango), *Gmelina arborea* L. (gmelina), *Citrus* spp. and many others. *Dioscorea esculenta* Burkh. (ñame) and *Colocasia esculenta* (L.) Schott (taro) are among the nontree hosts. No coniferous tree hosts are known.

Distribution—North, Central, and South America; Europe; Asia; Australia; the West Indies; American Samoa; and Hawaii. No tree hosts are known for the fungus in American Samoa and Hawaii. No record of the fungus could be found for Puerto Rico, Guam, and the Northern Mariana Islands.

Summary of Natural History and Basic Biology of the Pest—*Ceratocystis fimbriata* is a widely distributed pathogen that, in woody hosts, causes what is generally characterized as canker stain or vascular stain disease. The pathogen infects primarily through fresh wounds on the trunk or branches, rapidly invades the rays and vascular parenchyma of the sapwood, and to some degree moves through the vessels. Colonization of these tissues results in a brownish or grayish discoloration (Sinclair 1987). The discoloration sometimes extends into the heartwood. In some tree species (e.g., *Platanus* spp. and *Populus* spp.), the fungus may also kill the cambium, resulting in perennial cankers and eventual death of the tree when the trunk is girdled (Hinds 1972a, McCracken and Burkhardt 1977). The fungus has been reported to survive for at least 5 years in large pieces of wood of *Platanus acerifolia* buried in the soil (Grosclaude et al. 1995).

Ceratocystis fimbriata produces asexual (form genus *Chalara*) and sexual fruiting bodies (perithecia) on the surface of cankers and also on the cut surfaces of infected wood (e.g., on the cut end of logs or sawed timber). Both types of fruiting bodies produce sticky spores that easily are passively acquired and transported by a wide variety of insects (Hinds 1972b). Contaminated insects then may be attracted to fresh wounds through which infection occurs. Local spore dispersal may be accomplished by splashing water.

Because of its wide distribution in both tropical and temperate regions, as well as its numerous hosts, which include both woody and herbaceous plant species, considerable attention has been given to the possible occurrence of strains that may be pathogenic to a single host or groups of hosts. This has resulted in the formal recognition of one form, *C. fimbriata* f.sp. *platani*, that affects primarily *Platanus* spp. in the northern hemisphere (Walter et al. 1952). In the tropics, Wellman (1972) informally recognized "races" of the pathogen that were associated with rubber, cocoa, coffee, ñame and yautía (*Xanthosoma*), respectively. Other workers (e.g., Morgan-Jones 1967) have noted the occurrence of wide variation in host susceptibility to the pathogen, but no other formal recognition of *forma speciales* has been proposed.

Specific Information Relating to Risk Elements—

A. Likelihood of introduction

1. Presence with host or commodity at origin potential: *High* (*VC*) (Applicable risk criteria: c, d, e, f, g, h)
   Ceratocystis fimbriata is widely distributed in the tropics on numerous tree species that may be used as raw material for SWPM.

2. Entry potential: *High* (*VC*) (Applicable risk criteria: b, c, d)
   The fungus has been shown to survive for at least 5 years in large pieces of infected wood (Grosclaude et al. 1995). It is highly likely that the fungus would sporulate on the surface of infected wood under favorable environmental conditions. Smalley (personal communication) observed a *Ceratocystis* sp. fruiting on the surface of dunnage in Chile.

3. Establishment potential: *High* (*VC*) (Applicable risk criteria: b, c, d, e, f)
   The fungus produces chemical substances that attract a wide variety of insects. These insects, while crawling over the fruiting bodies of the fungus, acquire the sticky spores that then may be transported to fresh wounds on suitable hosts through which infection occurs.

4. Spread potential: *High* (*VC*) (Applicable risk criteria: a, c, d, f, g)
   Because of its sticky spores, *Ceratocystis fimbriata* is well adapted for dissemination through the passive activity of many types of insects.

B. Consequences of introduction

5. Economic damage potential: *High* (*RC*) (Applicable risk criteria: a, b, c, e)
   Ceratocystis fimbriata already is widely established in the continental United States on several important tree species as well as on sweet potato. It is generally agreed that considerable host specialization occurs in the species, with one pathogenic strain already formally described, and strong evidence exists that others may occur. The implications of introducing potentially different tropical strains of the fungus into the subtropical or even into temperate areas of the continental United States are not known, for there are no data on how tropical strains of the fungus would be affected by mainland U.S. environmental conditions. One potentially serious problem might be citrus, on which the fungus is reported to cause dieback in Colombia (Mourichon 1994). *Ceratocystis fimbriata* has been reported to cause cankers on deciduous fruit trees in California (DeVay et al. 1968) but has not been reported on citrus. Introduction of tropical strains into Hawaii and other Pacific Islands poses a potentially more serious risk. *Ceratocystis fimbriata* has been known to occur in Hawaii for many years on taro and *Syngonium podophyllum* Schott, which are both herbaceous species (Uchida and Aragaki 1979). However, *C. fimbriata* has never been found in Hawaii on coffee and mango, common hosts of the fungus in other tropical countries (Pontis 1952, Yamashira and Myazaki 1985), or on any other woody species. The situation is similar in American Samoa where the fungus has been found only on taro (E. Trujillo, personal communication). No record of the fungus was found for Guam or the Northern Mariana Islands.

   Once established, canker stain is difficult to control. Excising infected tissues at the canker margin and treating with a wound dressing has been suggested for control of the disease on fruit trees (Devay et al. 1968). Prompt removal of dead infected trees will help reduce the inoculum level.

6. Environmental damage potential: *Moderate* (*MC*) (Applicable risk criteria: f)
   Serious damage from *Ceratocystis fimbriata* in the tropics generally has been associated with managed plantation crops or ornamental trees. No information has been found on ecosystem damage.

7. Social and political considerations: *High* (*MC*) (Applicable risk criteria: a, b, c)
   Damage to mango, which is widely planted by homeowners for shade and fruit as well as in small commercial plantations in Hawaii and other tropical islands would have significant social and political

consequences. The same would be true for coffee, which is a small but economically important crop in Hawaii, and *Spathodea campanulata*, a widely planted ornamental tree in the tropics (Herrera-Isla et al. 1989). Other woody tropical fruits and ornamentals might also be affected. On the basis of available information, damage to the forest ecosystem in Hawaii and other tropical islands would be minimal.

C. Pest risk potential: **High** (Likelihood of introduction = *High*; Consequences of introduction = *High*).

Pink Disease

Assessor—Charles S. Hodges

Scientific Name of Pest—*Erythricium salmonicolor* (Berk. & Broome) Burdsall [= *Corticium salmonicolor* Berk. & Broome; *Phanerochaete salmonicolor* (Berk. & Broome) Julich; *Pellicularia salmonicolor* (Berk. & Broome) Dastur; *Botryobasidium salmonicolor* (Berk. & Broome) Venkatarayan]. Anamorph: *Necator decretus* Massee. (Basidiomycota, Hyphodermataceae).

Scientific Names of Hosts—Occurs on a wide range of woody perennials in the tropics. These include such important commodity crops as *Hevea brasiliensis* L. (rubber), *Coffea* spp. (coffee), and *Theobroma cacao* L. (cocoa); fruits such as *Citrus* spp., *Malus* spp., and *Litchi chinensis* Sonn.; woody ornamentals such as *Cercis canadensis* L., *Gardenia* spp., *and Ilex* spp.; and commercial forest plantation species such as *Eucalyptus* spp., *Acacia* spp., and *Paraserianthes falcataria* (L.). Forsberg.

Distribution—Throughout the humid tropics in North, Central, and South America; Africa; Southeast Asia; Australasia and Oceania; and some Pacific Islands (Anino 1990, Mordue and Gibson 1976). In the United States it is present in Florida, Louisiana, and Mississippi (Alfeiri et al. 1994, Tims 1963). It has not been reported in Hawaii, Guam, the Northern Mariana Islands, American Samoa, or Puerto Rico. Because of the favorable environmental conditions for disease development and numerous susceptible hosts, these island groups are at risk should the pathogen be introduced.

Summary of Natural History and Basic Biology of the Pest—*Erythricium salmonicolor* is widely distributed in the tropics, where it causes branch and stem cankers on a wide variety of woody hosts—primarily hardwoods. The fungus is able to penetrate intact bark usually through lenticels (Seth et al. 1978), where it may then kill the cambium; or, the cambium may be infected directly through wounds. In the wood, the fungus spreads longitudinally through the vessels and radially through the ray parenchyma (Subramaniam and Ramaswamy 1987). Small branches or stems may quickly be girdled, and distal portions are killed. Epicormic branches may be formed below girdling cankers and keep the tree alive. However, these may be infected and killed in future infection cycles, resulting in eventual death of the tree.

Erythricium salmonicolor produces four types of growth forms on the bark of infected trees. These have been designated the cobwebby, pustule, necator, and pink incrustation stages (Seth et al. 1978). The cobwebby stage appears as a thin layer of vegetative mycelium soon after infection on the surface of the bark during periods of rainy weather. This is followed quickly by the formation of pustules, which are pink-to-salmon colored sterile cellular structures. The necator and pink incrustation stages are formed later when the infected branches and stems are in the process of dying. The necator stage (*Necator decretus*) consists of orange fruiting bodies (sporodochia), which produce conidia. The pink incrustation stage is the perfect state of the fungus and produces basidiospores. Both conidia and basidiospores are spread by wind and are capable of causing infection through intact bark tissues, but basidiospores are believed to be the most important (de Almeida and Luz 1986). Serious damage from the disease usually occurs only in areas with rainfall above 2000 mm (80 inches) per year (Seth et al. 1978). There is no evidence of pathogenic specialization in the fungus.

Specific Information Relating to Risk Elements—

A. Likelihood of introduction

1. Presence with host or commodity at origin potential: *High* (*RC*) (Applicable risk criteria: c, d, e, g, h)
   Erythricium salmonicolor occurs on several species of commercial forest plantation trees in the tropics (e.g., *Eucalyptus* spp. and *Acacia* spp.) that might reasonably be used for SWPM. Other woody hosts, such as rubber, may also be harvested for production of low-quality lumber such as that used in pallets.

2. Entry potential: *High* (*MC*) (Applicable risk criteria: b, c, d)
   Nothing is known about length of survival of the fungus on the surface of the bark or in the wood. It is likely, however, that fruiting bodies on bark would be able to produce spores over a period of several months given favorable environmental conditions. Production of fruiting bodies on the surface of sawed infected wood has not been demonstrated but may be possible.

3. Establishment potential: *High* (*VC*) (Applicable risk criteria: b, c, f)
   Many of the known hosts of *Erythricium salmonicolor*, especially fruit trees, might reasonably be expected to occur in close proximity to ports or airports and be in easy range of windborne conidia or basidiospores.

4. Spread potential: *Moderate* (*VC*) (Applicable risk criteria: a, c, d, g)
   Given favorable conditions, especially high rainfall, for the production of conidia and basidiospores, and more or less constant breezes, spread from the point of initial infection would be rapid in view of the large number of potential hosts. Because most of the tropical islands at risk (e.g., Hawaii) are small in area, spread throughout the island of initial colonization might be accomplished in a period of a few months or at most 1–2 years after introduction.

B. Consequences of introduction

5. Economic damage potential: *Moderate* (*RC*) (Applicable risk criteria: a, b, c)
   Economic losses in the Southeastern United States where the fungus currently is present have been relatively low because of generally unfavorable climatic conditions for infection and spread. However, in parts of Hawaii and other Pacific Islands, climatic conditions are highly favorable for the pathogen. Although the actual dollar value of potential losses in these relatively small island groups would be fairly low, economic losses relative to the total value of commercial fruit orchards, home fruit trees, ornamental plants, and commercial forestry plantations could be high. Control of pink disease historically has been by application of Bordeaux mixture to new infections. This is difficult in most tree crops because the infections may occur in the crown and are not easily seen. In crops of relatively low value (e.g., forest trees), control is usually not economical. Research on new chemicals may provide more effective and economical control of the disease (e.g., see Duong et al. 1998).

6. Environmental damage potential: *High* (*MC*) (Applicable risk criteria: a, c, d)
   Because of the wide host range of the pink disease fungus, some of the many endemic species would likely be affected in areas where climatic conditions are favorable for infection and spread. Some of the endemic woody species in these tropical islands are on the threatened or endangered list. Many of the amenity trees and woody ornamentals commonly used in these island groups are known to be susceptible to the disease.

7. Social and political considerations: *High* (*MC*) (Applicable risk criteria: a, b, d)
   Because of the importance of the fruit and amenity plantings to the residents as well as to tourists, introduction of this pathogen to Hawaii and other island groups could result in serious social and political impacts.

C. Pest risk potential: **High** (Likelihood of introduction = *Moderate*; Consequences of introduction = *High*).

Wood Borers

Asian Longhorned Beetle

Assessor—Joseph F. Cavey

Scientific Name of Pest—*Anoplophora glabripennis* (Motschulsky) (Coleoptera: Cerambycidae)

Scientific Names of Hosts—*Acer negundo* L., *A. nigrum* Michx. F., *A. platanoides* L., *A. pseudoplatanus* L., *A. rubrum* L., *A. saccharinum* L. (= *A. dasycarpum*), *A. saccharum* Marshall, *A. truncatum* Bunge, *Aesculus glabra* Willd., *A. hippocastanum* L., *Albizia julibrissin* (Willd.) Durazz., *Alnus* spp., *Betula populifolia* Marsh., *Elaeagnus angustifolia* L., *Fraxinus excelsior* L., *F. pennsylvanica* Marshall, *Hibiscus syriacus* L., *Melia azedarach* L., *Morus* spp., *Populus* spp., including *P. alba* L. and *P. canadensis* Moench, *Prunus* spp., *Pyrus* spp., *Salix babylonica* L., *S. matsudana* Koidz, *Robinia pseudoacacia* L., *Ulmus pumila* L.

Distribution—China, Korea, and Japan (Haack et al. 1997a). (The few Japanese records from the literature probably reflect adventive beetles. No current population of *Anoplophora glabripennis* is known to occur in Japan.) Localized, quarantined populations exist in the United States in New York and Illinois under a continuing eradication program.

Summary of Natural History and Basic Biology of the Pest—*Anoplophora glabripennis*, commonly known in North America as the Asian longhorned beetle (ALB), is an important pest of poplar plantations (Yan 1985), windbreaks, and ornamental plantings in eastern China. It attacks primarily the trunks and branches of healthy and weakened hardwood trees.

In China, the ALB requires either 1 or 2 years to develop completely from egg to adult (Li and Wu 1993, Xiao 1980), and less than 20 percent require 2 years (Zhang, in press). It overwinters in the egg, pupal, or, most commonly, in the larval stage (Li and Wu 1993). Throughout the beetle's range in China, adults emerge from April or May to October (Li and Wu 1993; Thier 1997; Zhang, in press) with adult activity peaking in July. In New York and Illinois, they emerge at least from July to November. In the laboratory, peak emergence occurred 20 days after first emergence, for both sexes (Li and Wu 1993). New adults usually take about 7 days to exit their host, leaving almost perfectly round holes measuring 6–12 mm. Exit holes usually occur above their respective oviposition sites. The lifespan of adults ranges from 3 to 66 days with males ranging from 3 to 50 and females from 14 to 66 days (Xiao 1980). Adults are diurnal, most active from 8:00 a.m. – 12:00 p.m., and are not attracted to lights (Li and Wu 1993).

Beetles are generally most active on warm sunny days. On cloudy days or when temperatures exceed 33 °C (87 °F), adult activity decreases with the beetles normally remaining in tree crowns and sheltered areas. Adults are weak flyers capable of 1,000–1,200-m distances but often flying only 50–75 m (Thier 1997). Adults feed on host twigs, leaves, and leaf petioles usually for 2–3 days before mating (Zhang, in press).

Mating occurs on host branches and trunks, peaking in the afternoon (from 12:00–2:00 p.m. [Xiao 1980]; from 2:00-6:00 p.m. [Li and Wu 1993]). Adults are capable of copulating immediately upon emergence from the pupal stage. Males are fertile upon emergence, but females may take 10 days to mature sexually (Li and Liu 1997). Females usually mate and lay eggs more than once, but 8 percent of females never mate in the laboratory (Li and Wu 1993).

He and Huang (1993) found that a female pheromone directs ALB male orientation at a short distance, but visual stimulation elicits mating behavior at even closer range. For a species closely related to the ALB, *Anoplophora chinensis* (Forster), Wang (1998) reported that the host tree attracts aggregations of beetles, whereas the female pheromone is likely a contact pheromone used to attract males already present on the host.

Although not unique, the ALB's feeding habits are unusual. Most temperate cerambycids inhabit recently dead or dying wood (Haack and Slansky 1987), but the ALB commonly infests living, healthy, and weakened trees (Yan 1985, Mastro and Cavey 1996, Haack et al. 1997a). Most wood-feeding insects that inhabit living wood are monophagous (Haack and Slansky 1987), whereas the ALB is broadly polyphagous.

The ALB attacks a wide variety of hosts throughout its range; its larvae were successfully fed 23 species of poplar and 24 other tree species (Yang et al. 1995). This beetle prefers maple, poplar, and willow. In Asia, other hosts include mulberry, plum, pear, elm, and chinaberry. Black locust, plane-tree, and alder are also listed (Li and Wu 1993). A citation for "Citrus?" is very likely in error because of misidentification of the beetle.

In New York and Chicago, the beetle has also completed development on birch, horse chestnut, green ash, and Rose-of-Sharon (*Hibiscus syriacus* L.) and laid eggs on Japanese maple (*A. palmatum* Thund.), oak (*Quercus*), apple (*Malus*), Tree-of-Heaven (*Ailanthus altissima* [Miller] Swingle), white ash (*Fraxinus americana* L.), and London plane tree (*Platanus aceriflia* [Ait.] Willd.) (V. Mastro 1999, personal communication).

Female beetles lay an average of 32 eggs during an average 11-day period (Xiao 1980). To oviposit, females chew oval-to-circular depressions measuring about 1 cm through the bark to the phloem, lay a single egg in each pit, and cover the egg with a secretion that hardens to a protective layer. Females oviposit almost anywhere on the tree, including the trunk to the ground, on all but the smallest branches (to 3 cm), and even on exposed roots. In China, peak oviposition occurs in June to July, but egg laying continues into the fall. Most eggs hatch in 1–2 weeks, but those laid in September and October do not hatch until spring (Xiao 1980).

Xiao (1980) reported that new larvae eat phloem. At 2months, they begin eating bark and xylem and excrete frass from the oviposition hole. By 4 months, (third instar) larvae begin penetrating the xylem to nearly 4 cm behind the bark. Their tunnels begin horizontally and gradually bend upward, ranging from 3.5 to 15.0 cm and averaging 9.6 cm in length. Badly infested trees exhibit large amounts of coarse, fibrous, excelsior-like frass in tree crotches and on the ground, and sap flows from oviposition sites. Older larvae rest at their tunnel's end in the heartwood but periodically return to the area between xylem and phloem to feed. Pupation occurs in a widened chamber located at the end of the larval tunnel, and the pupal stage varies from 13 to 24 days (Xiao 1980; Zhang, in press).

Specific Information Relating to Risk Elements—

A. Likelihood of introduction

   1. Presence with host or commodity at origin: *High* (*VC*) (Applicable risk criteria: a, b, c, d, e, g, h)
      The ALB is a serious pest of poplar in China, where this tree is grown on large plantations for lumber and other purposes. The beetle often degrades poplar wood to cheap third-grade wood suitable for few uses other than packing material. The ALB damages a wide range of other hardwood trees that may also be used to pack export cargo. The beetle's habit of attacking living or recently cut trees, lengthy emergence period, and 1–2 year life cycle contribute to its presence in wood cut at any time of year. Repeated interceptions of the ALB in wood with cargo from China (discussed in the next paragraph) confirm its presence in wood packing materials.

   2. Entry potential: *High* (*VC*) (Applicable risk criteria: a, b, c, d)
      APHIS frequently intercepts longhorned beetle larvae in cargo from China, but taxonomists can rarely recognize this life stage to the species level. Because larvae of most species are unknown, intercepted larvae are usually identified to the genus level (e.g., *Anoplophora* sp.), subfamily level (e.g., Lamiinae), or family level (e.g., Cerambycidae). In the case of the ALB, USDA Agricultural Research Service specialists developed the ability to recognize larvae as genus *Anoplophora* in 1996.

APHIS–Plant Protection and Quarantine (PPQ) intercepted organisms recognized as Asian longhorned beetles only twice and as "*Anoplophora* sp." 21 times, from 1985 to 1998 (USDA APHIS 1998). However, APHIS–PPQ probably intercepted this species before 1996 repeatedly, but taxonomists could not recognize larvae to species. Consequently, some of the 26 previous interceptions from Chinese cargo associated with SWPM identified as "Lamiinae sp." or "Cerambycidae sp." (i.e., the subfamily and family containing the ALB) may represent unrecognized Asian longhorned beetles (USDA APHIS 1998). Cavey et al. (1998) noted a strong similarity between larvae of *Monochamus* and those of the ALB. This similarity suggests that some of the 141 *Monochamus* interceptions from China predating 1996 may also represent unrecognized Asian longhorned beetles (USDA APHIS 1998). The ALB was also intercepted from SWPM with Chinese cargo in the United Kingdom in 1998 and in Canada in 1992, 1996–1997, and 1998 (Dawson et al., n.d.; Canadian Food Inspection Agency 1998; Canadian Food Inspection Agency and Canadian Forest Service 1998).

But regardless of how many interceptions actually represent the ALB, this beetle has repeatedly entered North America. ALB populations currently infest trees in four locations on Manhattan and Long Islands in New York, and five locations near Chicago, IL. Asian longhorned beetles and larvae identified as "*Anoplophora* sp." associated with Chinese cargo have escaped detection at ports of entry and were found in warehouses in numerous States within the United States (USDA APHIS 1998) and in Canada (Canadian Food Inspection Agency and Canadian Forest Service 1998).

3. Establishment potential: *High* (*VC*) (Applicable risk criteria: a, b, c, d, f)
On the basis of extrapolations from its range in China, from 21°N. to 43°N. (and 100–127°E.), the ALB could become established in suitable areas of North America from southern Mexico to the Great Lakes (Haack et al. 1997a). The ALB feeds on a wide variety of hardwood tree hosts in China and in the United States, including maples, elm, birch, willow, and poplar (Haack et al. 1997a, Kucera 1996, Li and Wu 1993, Mastro and Cavey 1996, Xiao 1980). One study reported that larvae successfully fed on 23 species of poplar (*Populus*) and 24 other tree species in China (Yang et al. 1995).

   Outside of its native range, the ALB has infested trees in North America at locations on Manhattan ans Long Islands in New York (detected beginning in 1996) and at locations in and near Chicago, IL (detected beginning in 1998). Some of these infestations are estimated to be 10 years old (Haack et al. 1997a). Eradication efforts in New York have dramatically reduced but not eliminated local populations in the past 2 years. The ALB's persistence in New York, presence in Illinois, temperate Asian distribution, and wide host range indicate high potential for colonizing North America.

4. Spread potential: *Moderate* (*MC*) (Applicable risk criteria: b, d, e, g)
The ALB possesses a low intrinsic dispersal rate. Adults are weak flyers capable of 1,000–1,200-m distances, and infestations spread slowly, less than 300 m/yr in Beijing poplar groves (Thier 1997). The beetles are not attracted to lights (Li and Wu 1993). However, like other wood borers, the ALB can be transported as eggs, larvae, and pupae in logs, tree trimmings, firewood, and untreated lumber. As evidenced by thriving populations in six United States quarantine areas in New York and Illinois, the ALB apparently survives well in ornamental and shade plantings in urban and suburban areas. In such nonrural areas, wind-felled branches and dead or dying trees infested with ALB are very likely to be removed and transported away. Strong evidence indicates that the Amityville, NY, ALB infestation resulted from infested tree trimmings transported from the Brooklyn, NY, ALB quarantine area by a pruning company. Infestations in New York and Illinois were estimated as 10 years old, indicating that the ALB's presence may not be readily apparent in early stages of infestation, thereby allowing ample time for spread before detection.

B. Consequences of introduction

5. Economic damage potential: *High* (*RC*) (Applicable risk criteria: a, b, c, d, f)
The ALB shares certain characteristics with the European gypsy moth. Both pests are polyphagous, spread slowly, became established first in urban areas, and took an estimated 10 years after accidental introduction to become noticed (Tyrrell 1996). But unlike the gypsy moth, the ALB is perennially a serious pest in its native land despite the presence of coevolved natural enemies and varied control efforts over the years.

Literature on the ALB's economic and environmental effects in China is either sparse or not readily available. Electronic searches and inquiries through contacts in China have produced references mostly on ALB control research efforts (e.g., Dai and Wang 1988, Chen et al. 1990, Gao and Zheng 1997, Ho-shan 1976, Jiang et al. 1991, Lei et al. 1993, Liang et al. 1997, Liu et al. 1992, Qin et al. 1985, Sun et al. 1990). The variety and number of ALB control projects in China suggest that the ALB has significant adverse impact in its native habitat. Other literature, including a listing of the ALB with other forest pests (Gine and Chein 1986), reports that this beetle causes severe damage to forests (Sun et al. 1997, Yan 1985) and is the most serious pest of poplar in northeastern China (Schmutzenhofer et al. 1997), supports this conclusion.

Asian researchers have confirmed the ALB's pest status in China. Members of the Biological Control Institute of the Chinese Academy of Agricultural Sciences (CAAS) consider the ALB to be one of the most serious forest pests in China (J. Thaw 1997, personal communication). Discussion with Chinese scientists (R. Gao, Chinese Academy of Forestry Research, Institute of Forest Protection, and Y. Luo, Beijing Forestry University, Beijing) revealed that the ALB seriously reduces poplar fiber and wood production (B. Wang 1999, personal communication). Furthermore, it can affect agricultural crops indirectly by killing trees used as windbreaks around crop fields. In 1998, APHIS learned that the Chinese government ordered the removal and burning of large areas of poplar windbreaks to help reduce large numbers of the ALB in western China. Attempts to grow North American varieties of maple in China for wood and syrup production were recently abandoned because ALB repeatedly killed the trees (V. Mastro 1998, personal communication). This is consistent with severe decline and high mortality of many hardwood trees, especially maples, observed at ALB-infested areas in New York (Haack et al. 1997a, Mastro and Cavey 1996). In New York, the ALB infests healthy or stressed trees of all sizes, from newly planted saplings to mature plants measuring 1.8 m in diameter (Haack et al. 1997a). Apparently, beetles find trees suitable for laying eggs even if the trees are declining from previous ALB infestation. This habit renews infestation in already weakened trees, leading to eventual death of the tree. These reports and habits suggest that ALB would severely impact U.S. forest resources and related industries such as timber, nursery, tourism, and maple syrup.

Control efforts in New York and Illinois had resulted in the destruction of more than 5,560 trees by March 2000. The affected suburban areas lose esthetic and property value as mature infested trees are replaced by young, often less desirable ALB-resistant trees. Because efficacious control options are presently limited to tree removal, control costs are, and will likely remain, high (ALB control programs cost approximately $25.1 million from 1996 to March 2000) (M. Stefan, personal communication).

Like the United States, the European Union and Canada have initiated specific quarantine measures targeting wood with cargo from China to prevent introductions of the ALB. If the ALB spreads to lumber-producing areas in the United States, similar measures would likely be applied to U.S. exports.

The ALB is a major forest pest in China and in New York and Illinois has demonstrated formidable potential for harming many tree species in the United States.

6. Environmental damage potential: *High* (*RC*) (Applicable risk criteria: a, c, d, e)
The ALB has the potential to alter North American ecosystems owing to its tree-killing and polyphagous

habits and potential for widespread distribution on the continent. The pest has attacked host species in North America not recorded as hosts in Asia (including horse chestnut) and may find more suitable hosts in areas not presently infested. The majority of Canada's hardwood trees are susceptible to the pest (Canadian Food Inspection Agency 1998). The ALB is likely to alter dominant species composition and age structure in hardwood forests—especially those composed largely of maples or poplar. Because willows are among the ALB's preferred hosts, additional impact on wetlands may occur. Natural enemies and cultural methods for controlling the ALB are recorded from China (Dai and Wang 1988, Ho-shan 1976, Jiang et al. 1991, Liu et al. 1992, Qin et al. 1985, Sun et al. 1990), but the ALB remains a serious pest except where susceptible trees (poplars) are replaced with resistant varieties. Thus, for suppressing populations of the ALB in the North American environment, tree removal may remain a primary technique for some time, and chemical controls may become necessary should large-scale natural controls remain ineffective. Because the ALB develops in *Betula* and *Prunus*, the threatened species, *Betula uber* (Ashe) Fern., known only from Virginia and the endangered shrub plum, *Prunus geniculata* Harper, from Florida may be suitable hosts (http://plants.usda.gov/plantproj/plants/plntmenu.html, May 18, 1999).

7. Social and political considerations: *High* (*VC*) (Applicable risk criteria: a, b, c, d)
   ALB infestations and quarantine activities in urban and suburban areas of New York and Illinois have generated tremendous media interest since 1996. Numerous articles and video and audio spots periodically supplant the usual front-line news items to report citizen and community reaction to the pest. Citizens are disappointed that more mature (and often treasured) ornamental and shade trees killed by the ALB, removed for regulatory purposes, or both, must be replaced by often less-desirable nonhost saplings. Public perception of the ALB's potential threat to North American resources contributed significantly to emergency quarantine regulations enacted in the United States and Canada for SWPM from China and to passage of a North American Plant Protection Organization (NAPPO) standard for regulating these materials.

C. Pest risk potential: **High** (*VC*) (Likelihood of introduction = *Moderate*; Consequences of introduction = *High*).

A Sirex Woodwasp

Assessor—Dennis Haugen

Scientific Name of Pest—*Sirex noctilio* F. (Hymenoptera: Siricidae) and associated fungus *Amylostereum areolatum* (Fries) Boidin.

Scientific Name of Hosts—*Pinus* spp., especially *P. radiata* D. Don and *P. taeda* L.

Distribution—Native to Europe, Asia, and northern Africa; introduced to New Zealand, Australia, Brazil, Argentina, Uruguay and South Africa.

Summary of Natural History and Basic Biology of the Pest—*Sirex noctilio* is endemic to Europe, Asia, and northern Africa and reaches its greatest density in the Mediterranean zone (Spradbery and Kirk 1978, Medvedev 1993). *Sirex noctilio* is generally considered to be a secondary pest of trees following primary damage in its native range (Spradbery and Kirk 1978). It has become established in New Zealand (1900), Tasmania (1952), and the Australian mainland (1961), and more recently in Uruguay (1980), Argentina (1985), Brazil (1988), and South Africa (1994). In Australia and South America it causes significant tree mortality and is considered a major pest (Taylor 1981, Haugen and Underdown 1990, Oliveira et al. 1998).

Tree species attacked by *S. noctilio* in its native range are almost exclusively pines (e.g., *Pinus pinaster* Ait., *P. sylvestris* L., *P. nigra* Arnold, *P. pinea* L.), but it also has been recorded in fir (*Abies* spp.) and spruce (*Picea* spp.) (Spradbery and Kirk 1978). *Sirex noctilio* has been reported in larch (*Larix* spp.) and Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] (Krombein et al. 1979), but these reports are very rare occurrences or misidentifications. In New Zealand and Australia, the main host is *Pinus radiata* D. Don, a tree native to California. In Argentina, Brazil, and Uruguay, the main host is *Pinus taeda* L., a tree native to the Southeastern United States. Other known host species include, *Pinus elliottii* Engelm., *P. echinata* Mill., *P. palustris* Mill., *P. patula* Schiede & Dieppe, *P. caribaea* Morelet, *P. khasya* Royle (= *P. kesiya* Royle ex Gordon), and *P. strobus* var. *chiapensis* Martinez (Duraflora 1993, Maderni 1998). When stressed, any *Pinus* spp. appears to be susceptible to attack by *S. noctilio*.

The fungus *Amylostereum areolatum* (Fries) Boidin occurs in close association with woodwasps, *Sirex* spp. (Talbot 1964). Talbot (1977) states, "specific species of *Sirex* carry only one species of *Amylostereum*. In the case of *A. areolatum*, it is only known to be carried by three species of *Sirex*, none of which are known from North America." These three species are *S. juvencus* L., *S. noctilio* F., and *S. nitobei* Matsumura (Talbot 1977). This fungus is on *Pinus* (Coutts 1969a, b, c).

Much of the research on *S. noctilio* has been conducted in Australia and New Zealand (Madden 1988, Nuttal 1989), and thus the following information relates to the situation in these countries. *Sirex noctilio* normally completes one generation per year in southeastern Australia, but a portion of a population may take 2 years in the cooler climates of Tasmania and New Zealand (Taylor 1981). In Australia, adults emerge from early summer to early winter with peak emergence in late summer or early autumn. Males usually predominate, with sex ratios of 4:1 to 7:1 (Morgan and Stewart 1966, Neumann and Minko 1981). Females are attracted to physiologically stressed trees after an initial flight, which is usually less than 2 miles but with the potential of 100 miles (R. Bedding, personal communication). They drill their ovipositors into the outer sapwood to inject a symbiotic fungus (*A. areolatum*) and a toxic mucus. If the tree is suitable, eggs are laid into the sapwood (up to three separate eggs at a drill site). The fungus and mucus act together to kill the tree and create a suitable environment for the development of larvae. Crown wilt does not occur until a cross section of wood in at least one part of the stem has been invaded and killed by the fungus. Fecundity ranges from 21 to 458 eggs, depending upon size of the female (Neumann and Minko 1981). The eggs usually hatch within 10 to 15 days, but some may overwinter in cooler climates. Unfertilized eggs develop into males, and fertilized eggs develop into females. All larval instars feed on the fungus as they tunnel through the wood. Larval galleries may penetrate to the center of a tree. The number of instars varies from 6 to 12, and the larval stage generally takes 10 to 11 months. Mature larvae pupate close to the bark surface, and adults emerge about 3 weeks later (Taylor 1981).

Specific Information Relating to Risk Elements—

A. Likelihood of introduction

1. Presence with host or commodity at origin: *High* (*VC*) (Applicable risk criteria: a, b, c, e, f, g, h)
   Sirex noctilio is likely to be found in SWPM produced in its native range. The likelihood is even greater for countries in which *S. noctilio* is introduced and outbreaks are occurring. Low-quality trees harvested from first thinnings of pine plantations have a high risk of being infested with *S. noctilio*, and these trees are frequently used to make packing crates and pallets. The larval stage of *S. noctilio* is found at all depths in the wood and would be present in untreated milled lumber from infested trees. Through the transport of infested crates and pallets, *S. noctilio* already has been transported to many parts of the world.

2. Entry potential: *High* (*VC*) (Applicable risk criteria: a, b, c, d)
   Survival of *S. noctilio* larvae in SWPM can be very high. Survival greatly depends on a suitable moisture content for fungal growth (e.g., above 20 percent ODW [oven-dried weight]) (Talbot 1977). Survival of pupae and adults within the untreated wood would be very high. Because its life cycle is generally a year or longer, *S. noctilio* could easily survive the transit period within the wood and escape detection at the port of entry. Siricids are the most common Hymenoptera intercepted at ports of entry (Haack and Cavey 1997).

3. Establishment potential: *High* (*VC*) (Applicable risk criteria: a, b, c, d, e, f)
   Sirex noctilio appears to attack any species of *Pinus* successfully. A high likelihood of establishment is expected for pines within a 5-mile radius of ports of entry and SWPM destinations. Abundance of pine plantations in the susceptible age class within close proximity to the entry location would significantly increase the establishment potential. On the basis of its native range in Europe and Asia, *S. noctilio* could become established in any climatic zone of the continental United States where *Pinus* spp. grow.

4. Spread potential: *High* (*VC*) (Applicable risk criteria: a, b, c, d, e, f, g)
   If *S. noctilio* becomes established, it is likely to spread throughout the United States. Natural dispersal of *S. noctilio* has been estimated at 5 to 15 miles per year in Australia (Haugen et al. 1990). Adult females are capable of long dispersal flights and have high fecundity. Also, populations could be transported and established throughout the United States by movement of infested logs and lumber.

B. Consequences of introduction

5. Economic damage potential: *High* (*VC*) (Applicable risk criteria: a, b, c, d)
   Sirex noctilio has the potential to cause significant mortality in overstocked pine plantations and stressed forest stands. In Australia, *S. noctilio* caused up to 80-percent tree mortality in *Pinus radiata* plantations. In 1 year, *S. noctilio* killed 1.75 million trees in 141,000 acres of plantations aged 10 to 30 years (Haugen and Underdown 1990). The potential damage due to *S. noctilio* in Australia was estimated at $A1–4 billion (. $1–3 billion in 1998 U.S. dollars) for each rotation (R. Bedding, personal communication).

   An introduced population of *S. noctilio* would potentially have significant economic losses in *P. taeda* plantations in the Southeastern United States. Pine forests of the Western United States could be impacted by *S. noctilio* introduction. The susceptibility of the commercial western pine species to *S. noctilio* attack is not known. However, even with a conservative estimation of tree mortality, an economic analysis projected losses of $24–$130 million (. $28–$154 billion in 1998 dollars) in the Western United States (USDA Forest Service 1992).

An efficient biological control agent is available that can reduce and maintain *S. noctilio* populations below the economic damage threshold. A parasitic nematode, *Deladenus siricidicola* Bedding, can be mass produced and inoculated into *S. noctilio* populations as they invade and colonize new territories (Bedding 1972; Bedding and Akhurst 1974, 1978). The minimum cost to establish the nematode was estimated at $3.50 per acre (. $4.15 in 1998 dollars) in plantations (Haugen and Underdown 1990, Haugen et al. 1990, USDA Forest Service 1992), but a less intensive program could be implemented in natural stands compared with pine plantations.

6. Environmental damage potential: *High* (*RC*) (Applicable risk criteria: a, c, d)
The effect of *Sirex noctilio* on the native pine forests of the United States could be significant. Changes in stand composition could occur with the selective mortality of pines. The potential damage to these stands would be increased during droughts or other climatic events that reduce tree vigor. Also, an increase in *S. noctilio*-associated tree mortality may enlarge the populations of other destructive pests such as bark beetles or root rots. The introduction of *S. noctilio* into the forests of the United States would affect the populations of other insects. *S. noctilio* would be in competition with native siricids, and because *S. noctilio* is more aggressive, it might reduce populations of native species. An expanding *S. noctilio* population would result in population increases of the native parasites of siricids [e.g., *Rhyssa* spp., *Megarhyssa nortoni* (Cresson), *Schlettererius cinctipes* (Cresson), and *Ibalia* spp.)], which could further decrease the native siricid fauna (Kirk 1974, 1975; Taylor 1978). A significant reduction in the genetic base of *Pinus radiata* could occur if *S. noctilio* became established in the remaining native stands.

7. Social and political considerations: *High* (*RC*) (Applicable risk criteria: b, c)
Sirex noctilio has caused great concern around the world. Australia developed a national research program and a national fund for a biological control program in response *to S. noctilio* introduction on the mainland. Brazil views *S. noctilio* as the number one threat to its pine plantations and is implementing an intensive biological control program (Iede et al. 1998). Chile has been proactive in regulations to prevent *S. noctilio* entry and is monitoring for initial introductions and gaining expertise to implement a biological control program (Aguilar 1998).

C. Pest risk potential: **High** (Likelihood of introduction = *High*, Consequences of introduction = *High*).

Drywood Termites

Assessor—Michael Haverty

Scientific Name of Pest—Drywood termites (Isoptera: Kalotermitidae) in the genera *Cryptotermes* Banks [specifically *Cryptotermes cynocephalus* Light, *C. domesticus* (Haviland), *C. dudleyi* Banks, and *C. havilandi* (Sjöstedt)], *Incisitermes* Froggatt, *Kalotermes* Hagen, and *Neotermes* Holmgren.

Scientific Names of Hosts—Just about any hardwood or softwood could be infested.

Distribution—*Cryptotermes cynocephalus* is endemic to the Philippine Islands, where it attacks isolated boards in houses, and has recently been reported established in Hawaii (J.K. Grace 1999, personal communication). *Cryptotermes domesticus* occurs widely throughout the Indo–Malayan Region and in numerous islands and island groups over a wide area of the Pacific, but its exact origin is not known. It has been introduced into Panama and Guam (Gay 1969). *Cryptotermes havilandi* originates from Africa and has been introduced into northeastern South America, the island of Trinidad, and most of the other Lesser Antilles. Other reports of introductions may have been confused because of difficulties with the taxonomy of this group (Gay 1969). Where *C. havilandi* is endemic, it is widespread in wild habitats, occurring in living branches, dead parts of living trees, dry wood in stumps, fallen logs, but only rarely occurs in human habitations. Where it has become established in the Lesser Antilles, it has been responsible for extensive damage to houses (Gay 1969). Various species of *Incisitermes*, *Kalotermes*, and *Neotermes* could be problematic, but few have become established beyond their origin (Gay 1969). *Incisitermes minor* (Hagen), endemic to the southwestern United States, has become established in Japan, Hawaii, Louisiana, and Florida (R. Scheffrahn, personal communication). Also, most are not pests of structures where they are endemic.

Summary of Natural History and Biology of the Pest—Of the 2,300 species of termites known to exist in the world, only 183 are known to cause damage to structures, and of these, 83 have a significant economic impact. Termites are divided into three general categories: drywood, dampwood, and subterranean. Drywood termites account for less than 20 percent of the economically important species, and the genus *Cryptotermes* contains the largest number of economically important species (Gay 1969, Edwards and Mill 1986).

About 2 percent of the known species of termites are endemic to, or established in, the continental United States and Hawaii. There are at least 47 endemic and exotic species of termites in the contiguous United States. Of the 183 species noted for their potential for economic damage, only 17 occur in the United States (Su and Scheffrahn 1990). Control of drywood termites and repair of their damage result in a total economic impact to the United States of \$1.0 billion to \$1.5 billion (billion = 10^9) per year (N.-Y. Su 1999, personal communication).

All species of *Cryptotermes*, *Incisitermes*, *Neotermes*, and *Kalotermes* are drywood termites, which means that they need not maintain a connection with the ground or soil. They live entirely within the wood and do not absolutely require free water. In fact, some species, such as *C. brevis* (Walker), do not survive under conditions of high water content in the wood (Collins 1969). Most drywood termites are heavily protected from water loss by cuticular hydrocarbons and the cement layer on the cuticle. They adjust their water retention or excretion by absorbing water from their feces. In high humidity they excrete liquid fecal material; under dry conditions water is resorbed in the rectum, and fecal material is excreted as a pellet (Collins 1969). Owing to their ability to survive in wood with little moisture content, drywood termites can maintain viable colonies or portions of colonies for extended periods and would remain viable during transportation across vast stretches of land or water.

All species of drywood termites are social insects and live in colonies. They do not live in discrete nest structures. They live in a diffuse gallery system entirely within one or more pieces of wood. Individuals within this gallery system, including the reproductives, are mobile and can move within this system to areas with the most suitable environmental conditions (M. Rust 1999, personal communication). Generally, there are five types of individuals in a colony: immatures or larvae, workers, soldiers, reproductives, and nymphs. Nymphs will eventually metamorphose into adults with wings (alates) that serve to disperse and establish new colonies a significant distance (about 100 m) from the natal colony. Colonies contain a large proportion of workers and nymphs whose role is the care of the immatures, feeding and foraging, and cleaning, whereas the soldiers defend the colony from predators. The workers and younger nymphs are the individuals that damage the wood. Flights of the future reproductives (alates) can occur anytime during the year; however, they tend to disperse mostly over a 1- to 2-month "flight season."

Mature colonies can contain up to several thousand individuals, but even mature colonies never reach the size of mature subterranean termite colonies (Mampe 1990, Thorne 1998). Colonies as young as 4 years old can produce alates that fly off to establish new colonies (Mampe 1990). The untreated interior of treated poles and marine pilings are ideal sites for large colonies to fledge their annual production of alates. Incipient colonies can reinfest the same piece of wood occupied by the natal colony or other suitable wood nearby. To initiate a new colony alates need only find a gap or hole big enough for them to enter, seal off, and begin to excavate. Wood species is not a critical factor for pest species of drywood termites. Piles of pallets, crates, or other SWPM at port sites would be ideal for establishing new colonies. Workers and nymphs are capable of becoming replacement (neotenic) reproductives and assuming the reproductive role if the reproductives die or a portion of the colony is permanently separated from the main colony. It is this capacity for establishing new colonies by dispersal flights or from partial colonies or subcolonies that makes drywood termites a threat for introduction from nonendemic sites.

Cryptotermes species generally occur in tropical or subtropical areas, and numerous species are known to infest buildings. *Cryptotermes brevis* and *C. havilandi* have most frequently been introduced to new localities (Gay 1969, Edwards and Mill 1986). Where these species occur in exotic locations, they can cause extensive damage to buildings. For the purposes of this assessment, all species of *Cryptotermes*, *Incisitermes*, *Kalotermes*, and *Neotermes* should be considered dangerous if arriving at U.S. ports in SWPM.

Numerous other species of termites are mentioned by Edwards and Mill (1986) as significant pests of wood in buildings, but seldom have they been exported and established in other countries (Gay 1969), and they are therefore not detailed in this assessment.

Specific Information Relating to Risk Elements—

A. Likelihood of introduction

1. Presence with host or commodity at origin potential: *High* (*VC*) (Applicable risk criteria: a, c, d, e, f, g, h)
   Presence of the potential host species where the drywood termites are endemic is not the critical problem with drywood termites. If SWPM are left exposed in ports for an extended period where these termites live, they can infest nearly all SWPM. Just about any species of wood could supply harborage for the drywood termites listed in this assessment. The likelihood of infestation of SWPM by termites increases with long-term storage of wood at the export site. Likewise, just about any species of wood at the import site would be suitable for sustaining drywood termites.

2. Entry potential: *High* (*VC*) (Applicable risk criteria: a, b, c, d)
   Drywood termites could survive quite well during transit and may not be detected if they are within the wood. The most likely indication of the presence of drywood termites is the appearance of piles of characteristic fecal pellets on horizontal surfaces, but these pellets are usually not obvious until colonies are well established in the wood.

3. Establishment potential: *High* (*RC*) (Applicable risk criteria: a, b, c, d, e)
   With drywood termites, the presence of an acceptable host is not the critical factor. Rather, a suitable environment with an adequate supply of wood or cellulose and the appropriate temperature and moisture

regime are the key factors. The initiation of a colony is a slow process, but a successfully established pair of alates (male and female) in SWPM could easily survive the transit to the import site. Abundant SWPM, other infested wood, wooden structures, and cellulose-containing materials at ports and storage facilities may provide an infestation source. Reuse or long-term storage of infested SWPM at the site of export or import would greatly enhance the likelihood of introduction of drywood termites. The adults (alates) fly for only about 100 m but are capable of moving up to 1 km depending on wind conditions and weather. Colonization would be ideal in a warm, moist environment, but the most favorable circumstances are warm to hot maritime conditions.

4. Spread potential: *High* (*RC*) (Applicable risk criteria: a, b, c, d, e, g)
Termites spread slowly (15 to 300 m per year), and less than 1 percent of the alates eventually establish a new colony. However, an important factor concerning drywood termites is that infested SWPM, moved by humans in commerce, spread termites at a much faster rate than their natural spread. Also, once established at the receiving seaport, airport, or inland destinations (warehouses, etc.), drywood termites are often not detected because of their cryptic habits; colonies are large before the first evidence of their activities (piles of characteristic fecal pellets) is apparent. By this time, multiple colonies will already be established adjacent to the invading colony, and additional SWPM could become infested and distributed within the continental United States or its territories and possessions.

B. Consequences of introduction

5. Economic damage potential: *Moderate* (*RC*) (Applicable risk criteria: a, c)
Termites will attack untreated wood. Their damage to wooden houses can be severe if not detected at an early stage. Once they are in a structure, spread of drywood termites to other parts of the structure can be rapid, and the economic impact can be quite high. Most species of *Cryptotermes* probably would not do well in extremely cold climates but could be a problem in moist, warm climates along the western, southern, and southeastern coasts of the continental United States.

Drywood termites cause a small portion of the economic losses due to wood-destroying insects in the United States. However, where they are abundant (southern Florida, southern California, and Hawaii), the costs for control and repair of their damage rival that of subterranean termites. Potential economic losses caused by all species of *Cryptotermes*, but primarily *C. havilandi* and *C. dudleyi*, could be comparable with those currently caused by the exotic *C. brevis* and the endemic *Incisitermes minor* (Hagen). If *C. havilandi* or *C. dudleyi* were to be as aggressive as *C. brevis* and *I. minor*, an additional $100 million in damage and control costs within 30 years could result.

6. Environmental damage potential: *Low* (*VC*) (Applicable risk criteria: none)
These termites would not likely cause large outbreaks or kill an excessive number of trees. Drywood termites would most likely feed on dead wood in live trees or dead wood on the ground.

7. Social and political considerations: *Moderate* (*RC*) (Applicable risk criteria: a)
Drywood termites do not cause esthetic damage in forests. They can infest live trees by attacking pruning and fire scars. This could degrade the value of timber species grown where drywood termites live. Damage to wood in use would cause the consumer the greatest concern, adding to concerns about other termites species. Control methods for termites are available but can be expensive. Spot treatments do not eliminate the problem, and fumigant gases stop the infestation but provide no residual protection. Furthermore, one of the fumigant gases (methyl bromide) is being phased out owing to concerns over adverse effects to environmental quality through depletion of the ozone layer.

The successful establishment of any species of *Cryptotermes* in the United States or in one of its protectorates or possessions would probably be as damaging as *C. brevis* or *I. minor*.

C. Pest risk potential: **High** (Likelihood of introduction = *High*, Consequences of introduction = *Moderate*).

Subterranean Termites

Assessor—Michael Haverty

Scientific Name of Pest—Subterranean termites (Isoptera: Rhinotermitidae) in the genera *Coptotermes* Wasmann [specifically *Coptotermes acinaciformis* (Froggatt), *C. formosanus* Shiraki, *C. frenchi* Hill, *C. havilandi* Holmgren, *C. lacteus* (Froggatt), and *C. vastator* Light], *Heterotermes* Froggatt [specifically *Heterotermes philippinensis* (Light), *H. convexinotatus* Snyder, and *H. tenuis* (Hagen)], and *Reticulitermes* (Holmgren) [specifically *Reticulitermes chinensis* Snyder, *R. lucifugus* (Rossi) including all subspecies, and *R. speratus* (Kolbe)].

Scientific Names of Hosts—Just about any hardwood or softwood could be infested.

Distribution—*Coptotermes* and *Heterotermes* are Pantropical genera; *Reticulitermes* is a Palearctic genus. *C. acinaciformis*, *C. frenchi*, and *C. lacteus* are endemic to Australia but have been successfully introduced to New Zealand. *C. havilandi* appears to have originated from Southeast Asia or Indonesia but has become established in Madagascar, Mauritius, Brazil, the West Indies, and most recently in Florida (Su et al. 1997). *C. vastator* is native to the Philippines and is established in Guam (Su and Scheffrahn 1998a) and possibly Hawaii as well (Bess 1970). *C. formosanus* is now a circumtropical species that originated from south China and is well established in Japan, Taiwan, South Africa, Sri Lanka, Pakistan, Burma, Thailand, Hong Kong, Midway Island, the Marshall Islands, Hawaii (all major islands), and many locations in southeastern North America (Gay 1969, Bess 1970, Edwards and Mill 1986).

Heterotermes philippensis is native to the Philippine Islands and is not a major pest of buildings; however, where it has been introduced (Madagascar and Mauritius) it is a significant pest in structures. Where they are endemic in South America, *H. convexinotatus* and *H. tenuis* are significant pests in buildings. Furthermore, this is a refractory genus taxonomically, and it would be prudent to consider all species in this genus as potential exotic pests. An unidentified species of *Heterotermes* was recently found established in Miami, FL, (Scheffrahn and Su 1995).

Reticulitermes is yet another refractory genus. *R. lucifugus* is a significant pest of structures in southwestern Europe, and where it has been exported and established (Israel and Turkey), it has become a significant pest of buildings (Gay 1969, Edwards and Mill 1986). Two additional species, *R. chinensis* and *R. speratus*, are significant pests where they are endemic: China, Vietnam, and eastern India for the former, and Japan, Taiwan, and Korea for the latter. Neither *R. chinensis* nor *R. speratus* has yet been exported and established in another country.

Summary of Natural History and Biology of the Pest—Of the 2,300 species of termites known to exist in the world, only 183 are known to cause damage to structures, and of these, 83 have a significant economic impact. Termites are divided into three general categories: drywood, dampwood, and subterranean. Subterranean termites account for about 80 percent of the economically important species, and the genus *Coptotermes* contains the largest number of economically important species (Su and Scheffrahn 1998b).

About 2 percent of the known species of termites are endemic to, or established in, the continental United States and Hawaii. There are at least 47 endemic and exotic species of termites in the contiguous United States. Of the 183 species noted for their potential for economic damage, only 17 occur in the United States (Su and Scheffrahn 1990). Control of subterranean termites and repair of their damage in the United States results in a total economic impact of about $6.0 billion (billion = $\times 10^9$) per year [$1.5 to 2.0 $\times 10^9$ for control of subterranean termites and $4 $\times 10^9$ for repair of damage] (N.-Y. Su 1999, personal communication).

All species of *Coptotermes*, *Heterotermes*, and *Reticulitermes* are subterranean termites, which means that they must maintain a connection with the ground or soil unless a supply of water is otherwise available. When free water is available or wood is saturated with water, species in these genera can maintain viable colonies or portions of colonies for extended periods and remain alive during transportation across vast stretches of land or water. They can also establish aerial colonies in buildings. To attack wood above the ground, shelter tubes composed of wood, soil, and termite excrement are constructed to connect the colony with the source of wood they are exploiting.

All species of subterranean termites are social insects and live in colonies. Some species of *Coptotermes* are found in discrete nest structures and can construct mounds. The interior of *Coptotermes* nests contains a carton material, masticated wood of termite excrement, with numerous chambers that accommodate the reproductives, eggs, and immatures. *Heterotermes* and *Reticulitermes*, as well as some species of *Coptotermes*, live in diffuse nests, a dispersed aggregation of subnests. These subnest units are mobile and allow the entire colony, including the reproductives, to move to areas with the most suitable environmental conditions (Thorne 1998). Generally, there are five types of individuals in a colony: immatures or larvae, workers, soldiers, reproductives, and nymphs. Nymphs will eventually metamorphose into adults with wings (alates) that serve to disperse and establish new colonies a significant distance from the natal colony. Colonies contain a large proportion of wingless workers whose role is caring for the immatures, feeding and foraging, and cleaning, whereas the soldiers defend the colony from predators. The workers are the individuals that damage the wood. Flights of the future reproductives (alates) generally occur during spring, summer, or fall after rain but can occur anytime during the year in tropical environments.

Mature colonies contain several thousands to millions of individuals (Thorne 1998). Satellite colonies of the larger colonies can also be equivalent to an immature or young colony in size. Workers and nymphs are capable of becoming replacement (neotenic) reproductives and assuming the reproductive role if their satellite colony or subunit is permanently separated from the main colony. It is primarily this capacity for establishing new colonies (by budding) from satellite colonies or subcolonies that makes subterranean termites a threat for introduction from nonendemic sites.

Coptotermes species generally occur in tropical or subtropical areas, and numerous species are known to infest buildings. *Coptotermes formosanus* and *C. havilandi* have most frequently been introduced to new localities (Edwards and Mill 1986). Where these species occur in exotic locations, they cause extensive damage to buildings. *Coptotermes formosanus*, *C. havilandi*, *C. acinaciformis*, and *C. frenchi* often feed on live trees and eventually kill them or damage the root system and cause the trees to fall in heavy winds. *Coptotermes lacteus* feeds primarily on wood on the ground or wood in contact with the ground. *Heterotermes* and *Reticulitermes* also feed on wood in contact with the ground but will bridge gaps with foraging tubes to reach wood above ground. For the purposes of this assessment, all species of *Heterotermes* and *Reticulitermes* should be considered dangerous if arriving at U.S. ports in SWPM.

Numerous other species of termites are mentioned by Edwards and Mill (1986) as significant pests of wood in buildings, but seldom have they been exported and established in other countries (Gay 1969) and are therefore not detailed in this assessment. *Coptotermes formosanus* does occur in many locations along the coastal Southeastern United States, but it can still be introduced into susceptible U.S. localities and possessions such as the recent successful introduction in La Mesa near San Diego, CA.

Specific Information Relating to Risk Elements—

A. Likelihood of introduction

1. Presence with host or commodity at origin potential: *High* (*VC*) (Applicable risk criteria: a, c, d, e, f, g, h)
   Presence of the potential host species where the subterranean termites are endemic is not the critical problem with subterranean termites. If SWPM are left in contact with the soil for an extended period where these termites live, they can either infest the SWPM itself or establish a satellite colony within SWPM structures such as crates, pallets, and wooden spools. Just about any species of wood can supply harborage for the subterranean termites. The likelihood of association of subterranean termites with

SWPM increases with long-term storage of wood at the export site. Likewise, just about any species of wood at the import site would be suitable for sustaining subterranean termites.

2. Entry potential: *High* (*VC*) (Applicable risk criteria: a, b, c, d)
Subterranean termites can survive quite well during transit and may not be detected if they are within a moist cavity in the wood or within a carton nest and have access to free water during transit. Carton material or foraging tubes, however, would likely be spotted during inspection of the material. It might be difficult to spot carton nests of *Coptotermes* species in the center of wooden spools. The greatest danger exists if items are shipped from sites with these species present and remain in storage at the import site in a suitable habitat for an extended time. This is how *C. formosanus* was imported and established multiple times into the Southeastern United States in shipments of surplus military materiel.

3. Establishment potential: *High* (*RC*) (Applicable risk criteria: a, b, c, d, e, f)
With subterranean termites, the presence of an acceptable host is not the critical factor. Rather, a suitable environment with an adequate supply of wood or cellulose and the appropriate moisture conditions are the key factors. The initiation of a colony is a slow process, but additional SWPM, wooden structures, and cellulose-containing materials at ports and storage facilities may provide an infestation source. Reuse or long-term storage of infested SWPM greatly enhances the likelihood of introduction of subterranean termites. The adults (alates) fly only about 100 m but are capable of moving up to 1 km depending on wind conditions and weather. Long-range (> 10 km) dispersal of colonies from alates is very unlikely. Colonization is variable and depends on the genus; warm, moist conditions are conducive to *Coptotermes*; warm, dry conditions are favored by many *Heterotermes* species; and cool, moist conditions are most favorable to *Reticulitermes.*

4. Spread potential: *High* (*RC*) (Applicable risk criteria: a, b, c, d, e, g)
Termites spread slowly (15 to 300 m per year), and less than 1 percent of the alates eventually establish a new colony. However, an important factor concerning subterranean termites is that infested SWPM, moved by humans in commerce, spread termites at a much faster rate than their natural spread. Also, once established at the receiving seaport, airport, or inland destinations (warehouses, etc.), subterranean termites are often not detected because of their cryptic habits; colonies are quite large before the first evidence of their activities is apparent. By this time, multiple colonies will already be established adjacent to the invading colony, and additional SWPM could become infested and distributed within the continental United States or its possessions. Furthermore, subterranean species are often misdiagnosed or confused with endemic species.

B. Consequences of introduction

5. Economic damage potential: *Moderate* (*VC*) (Applicable risk criteria: a, b, c)
Termites will attack untreated wood. Their damage to wooden houses can be severe if not detected at an early stage. Once they are in a structure, spread of subterranean termites can be rapid, and the economic impact can be quite high. Most of these termites discussed here probably would not do well in extremely cold climates but could be a problem in moist, warm climates along the western, southern, and southeastern coasts of the continental United States and subtropical and tropical locations of the United States and its protectorates and possessions.

Subterranean termites cause the great majority of economic losses due to wood-degrading insects in the United States. Potential economic losses caused by all species of *Coptotermes*, but primarily *C. havilandi*, could be comparable with those currently caused by the exotic *C. formosanus*. Species of *Coptotermes* from Australia feed almost exclusively on species of *Eucalyptus*. They could pose a significant hazard to the numerous *Eucalyptus* trees planted as ornamentals, for windbreaks, or for fiber in much of California.

Control methods for termites are available but can be expensive and could be a risk to environmental quality through increased pesticide use. An exotic termite currently causing very significant economic damage in the United States is the Formosan subterranean termite (*Coptotermes formosanus*). This destructive species from central Asia costs more than $100 million in termite control treatments and damage repairs on the island of Oahu (Hawaii) alone (Hanson 1998). Damage in the French Quarter of New Orleans is rapidly increasing and could soon equal the costs in Hawaii (N.-Y. Su 1999, personal communication).

Any species of *Coptotermes* becoming successfully established in the United States or of one of its protectorates or possessions would probably be as damaging as other species of *Coptotermes* such as *C. formosanus*.

6. Environmental damage potential: *Low* (*RC*) (Applicable risk criteria: none)
   These termites would not likely cause large outbreaks or kill an excessive number of trees. Trees at greatest risk would be street trees, such as the ones injured by *C. formosanus* in Honolulu and New Orleans. These termites could compete with native termites that degrade and decompose wood in use. In fact, where *C. formosanus* is established in Florida and New Orleans, it does outcompete the native termite fauna.

7. Social and political considerations: *Moderate* (*RC*) (Applicable risk criteria: a)
   These termites generally do not cause esthetic damage in forests, although most *Coptotermes* species will consume the heartwood of live trees. However, damage to wood in use would cause significant consumer concerns, thus adding to concerns about other termites species.

C. Pest risk potential: **High** (Likelihood of introduction = *High*, Consequences of introduction = *Moderate*).

Bark Beetles

Red-Haired Pine Bark Beetle

Assessor—Andris Eglitis

Scientific Name of Pest—*Hylurgus ligniperda* (Fab.) (Coleoptera: Scolytidae)

Scientific Names of Hosts—*Pinus* spp. including *P. canariensis* C. Smith, *P. elliottii* Engelm., *P. halepensis* Mill., *P. brutia* (Ten.), *P. montezumae* Lamb., *P. nigra* Arnold, *P. patula* Schiede & Deppe, *P. pinaster* Aid., *P. pinea* L., *P. radiata* D. Don, *P. strobus* L., and *P. sylvestris* L. (Browne 1968).

Distribution—Throughout Europe, including Great Britain and the Mediterranean Basin (Schwenke 1974), Caucasus Mountains, and western Siberia; introduced into Japan and Sri Lanka (Browne 1968); introduced into the Republic of South Africa, Saint Helena, and Swaziland (Browne 1968); introduced into Australia (Neumann 1979) and New Zealand (Bain 1977); introduced into Brazil (Schönherr and Pedrosa-Macedo 1981) and Chile (Ciesla 1988a, unpublished).

Summary of Natural History and Basic Biology of the Pest—*Hylurgus ligniperda* normally infests fresh stumps and slash from recently felled trees (Ciesla 1988b). These beetles also attack buried logs or portions of logs in contact with the soil (Tribe 1992). On occasion, weakened or wounded standing trees will be infested (Fabre and Carle 1975). In Chile, *H. ligniperda* has been found in standing trees during periods of drought (L. Cerda Martinez 1992, personal communication). The beetle occasionally kills *P. radiata* seedlings (Neumann 1987, Ciesla 1988b).

Female beetles initiate attacks on suitable host material by boring through the bark and constructing a small maturation chamber beneath the bark. Males join the females, and mating takes place in these chambers. Females then construct a long, winding oviposition gallery and lay eggs in notches cut in the sides of the gallery. Up to 500 eggs may be laid by one female. Larvae feed beneath the bark and pupate once mature. Adults emerge and fly to new hosts at various times of the year because the insects generally complete more than one generation per year. In France, there are two generations per year (Fabre and Carle 1975) with first-generation adults laying eggs in the winter and spring and the second generation laying eggs in the fall. In Chile, *H. ligniperda* completes three generations in a year (Cogollor 1991, unpublished), and adults can be found in virtually every month of the year. In South Africa, adults are also present throughout the year but are most active during periods of cool temperatures and high humidity, peaking in the fall (April–May) with minor peaks in the spring (September) and summer (January) (Tribe 1991a,b).

Two species of the fungus *Leptographium* [*L. truncatum* (Wingf. & Marasas) Wingf. and *L. procerum* (Kendrick) M.J. Wingfield] have been isolated from New Zealand populations of *H. ligniperda* (Wingfield et al. 1988, MacKenzie 1992). *Leptographium truncatum* (a possible synonym of *L. lundbergii* Lagerberg & Melin [Wingfield and Gibbs 1991], which occurs in Canada) is a reported pathogen of *Pinus radiata* and *P. strobus* in New Zealand (Wingfield and Marasas 1983). Inoculation tests indicate that *L. truncatum* is not highly virulent and may be opportunistic (Wingfield et al. 1988). Procera root disease, caused by *L. procerum* (= *Verticicladiella procera* Kendrick) is an important disease of eastern white pines (*P. strobus*) in the Eastern United States (Sinclair et al. 1987), producing serious damage in Christmas tree plantations in Virginia (Lackner and Alexander 1982, 1984). Numerous other pines are also affected by *L. procerum*. The association of these fungi with New Zealand *H. ligniperda* is very high, for the fungus has been isolated from more than 70 percent of the beetles examined (MacKenzie 1992). In South Africa, *H. ligniperda* is commonly associated with *Ophiostoma* (= *Ceratocystis*) *ips* (Rumbold) Nannf., and *Leptographium serpens* (Goid.) Siemaszko [= *Ophiostoma serpens* (Goid.) von Arx], and an unidentified *Leptographium* sp. (Wingfield et al. 1985). Symptoms of a black-staining root disease have been noted on some *Hylurgus*-infested Monterey pines in Chile (Ciesla 1988b; Gara et al. 1988, unpublished), but the causal agent has not been identified.

Specific Information Relating to Risk Elements—

A. Likelihood of introduction

1. Presence with host or commodity at origin potential: *High* (*VC*) (Applicable risk criteria: a, c, d, e, f, g, h)
   Hylurgus ligniperda is strongly attracted to freshly cut logs (Ciesla 1988b). Because the adult stage of the insect occurs throughout most of the year (Cogollor 1991, unpublished), attacks can occur on logs cut at virtually any time. Live insects could readily be associated with boards cut from those logs if they contained bark.

2. Entry potential: *High* (*VC*) (Applicable risk criteria: a, b, c, d)
   The introduction of *H. ligniperda* into many parts of the world and its continued interception in ports in association with SWPM is a strong testimonial to its host association and survival capability in this substrate. Between 1995 and 1998, after the regulation for bark-free SWPM came into effect, *H. ligniperda* was intercepted in U.S. ports on 20 occasions in association with SWPM. Most of these interceptions were of European origin.

3. Establishment potential: *High* (*RC*) (Applicable risk criteria: a, b, c, d, e, f)
   Several of the known pine hosts for *H. ligniperda* occur in various parts of the United States. Given its broad host range within the genus *Pinus*, it seems likely that *H. ligniperda* could adapt to additional pines if given the opportunity. The beetle could colonize stumps, fallen branches, and moribund trees if this material were present around the port of entry or the final destination point for infested SWPM.

4. Spread potential: *High* (*RC*) (Applicable risk criteria: a, b, c, d, e, f, g, h)
   Adults can disperse over distances of several kilometers (Fabre and Carle 1975), and an infestation can spread as long as host material is available. This strong capability of spread has been demonstrated in Australia (Neumann 1987), where *H. ligniperda* spread up to 25 km from a fire-killed area within 18 months, and in Chile, where the beetle now occupies the entire distribution of Monterey pine after being introduced into the country in the mid-1980's. *Hylurgus ligniperda* has demonstrated a competitive advantage over at least two similar species. *Hylurgus ligniperda*, *Hylastes ater*, and *Orthotomicus erosus* were introduced into Chile in the 1980's. Although the initial distributions, habitats, and abundance were similar, *H. ligniperda* eventually supplanted the other two species throughout the country. (In his study of *H. ligniperda* and *H. ater* in Chile, Cogollor [1991, unpublished] noted that only *H. ligniperda* was abundant in plantations of *P. radiata*).

B. Consequences of introduction

5. Economic damage potential: *High* (*MC*) (Applicable risk criteria: b, c, d, f)
   A concern over the introduction of *H. ligniperda* is its potential as a vector of black-stain root disease [caused by *Leptographium wageneri* (Kendrick) M.J. Wingfield], which affects pines in the United States. The association of *Leptographium* spp. with *H. ligniperda* is very high (MacKenzie 1992). Even if exotic species of this fungal group did not produce pathogenic effects similar to the native black-stain root disease, there could also be the potential for *H. ligniperda* to become a more efficient vector for black-stain root disease than the native vectors present in the United States on the basis of the efficiency of spread it has demonstrated in other environments such as Chilean plantations of Monterey pine (Cogollor 1991, unpublished). *Hylurgus ligniperda* is occasionally a mortality agent (Neumann 1987, Ciesla 1988b) and can infest seedlings or pole-sized trees if they are growing under stressed conditions.

6. Environmental damage potential: *Moderate* (*RC*) (Applicable risk criteria: d)
   If *H. ligniperda* were introduced and became a more efficient vector of the fungus that causes black-stain root disease, its activity could result in greater damage to the pine component of mixed-species forests. There could also be environmental concerns if this beetle–fungus relationship led to greater levels of pesticide use as a result of increased tree damage. Currently, the fungus *L. procerum* is uncommon in the Northwestern United States (Sinclair et al. 1987), although it has been detected there on occasion (D. Goheen 1999, personal communication). The introduction of *H. ligniperda* could broaden the distribution of this occasionally pathogenic fungus to pine forests or Northwestern Christmas tree plantations not previously exposed to the fungus that causes procera root disease. Other ecological effects of introduction could include the displacement of native bark beetles, such as *Hylastes* spp. and *Dendroctonus valens* LeConte, which occupy the same niche as *H. ligniperda.*

7. Social and political considerations: *Moderate* (*RC*) (Applicable risk criteria: c)
   If the beetle became established as a successful vector of the black-stain root disease pathogen, there could be ramifications for international trade because *H. ligniperda* is a quarantine-significant pest for numerous countries.

C. Pest risk potential: **High** (Likelihood of introduction = *High*; Consequences of introduction = *High*).

European Spruce Bark Beetle

Assessor—Andris Eglitis

Scientific Name of Pest—*Ips typographus* (L.) (Coleoptera: Scolytidae) and the associated fungus *Ceratocystis polonica* (Siemaszko) Moreau.

Scientific Names of Hosts—*Picea* spp. (spruce), including *P. abies* (L.) Karsten (= *P. excelsa* Link) (Norway spruce) and *P. jezoensis* (Siebold & Zuccarini) Carriere; *Pinus* spp. (pine); *Larix* spp. (larch).

Distribution—In Europe and Asia throughout the range of Norway spruce; Belgium, France, northern Norway, Sweden, Finland, northern Italy, Yugoslavia, the Czech Republic, Bulgaria, eastern Russia, China, Japan.

Summary of Natural History and Basic Biology of the Pest—*Ips typographus* normally infests down material including logs, slash, and windthrown trees. Spruce is the preferred host although attacks can also occur on pines and larches. In fact, in the Caucasus, *Pinus* spp. is the basic food plant for *I. typographus* (Krivolutskaya 1983). The beetle can cause severe losses in the forest when populations build up in down host material and subsequent generations infest standing trees. Infestations are generally most severe in stands greater than 120 years old (Christiansen and Bakke 1988). In an outbreak in Germany, stands less than 40 years old sustained very little damage (Christiansen and Bakke 1988).

The European spruce bark beetle has a number of associated fungi that it introduces into the host trees as it infests them. One of these fungi, *Ceratocystis polonica* (Siemaszko) Moreau (= *Ophiostoma polonicum* Siem.), is highly virulent and capable of killing the host by itself when artificially inoculated into healthy spruce trees (Horntvedt et al. 1983). Other *Ceratocystis* species and a *Graphium* species are also associated with the beetle (Furniss et al. 1990). Yamaoka et al. (1997) list nine species of Ophiostomatales fungi associated with *I. typographus* in Norway and Japan.

Ips typographus overwinters in the adult stage, generally in the duff near the tree where it developed (Christiansen and Bakke 1988). A smaller number of individuals remain beneath the bark for the winter, especially in the southern part of the insect's range (Christiansen and Bakke 1988). Adults mature in the spring before taking flight (Forsse and Solbreck 1985). Dispersal flights are initiated in response to air temperatures of 20 °C, which, depending on latitude and altitude, can occur from April to June in Europe (Bakke et al. 1977).

A complex system of chemical communication governs the host selection process. Male beetles find suitable hosts, probably in response to tree odors, and then initiate attacks. The males produce pheromones that aggregate both sexes to the host material under attack. Once the host material is fully colonized, the insects produce antiaggregant chemicals that lead to cessation of further attacks. Male beetles are the principal producers of these semiochemicals, some of which are derived from host monoterpenes (Vité et al. 1972).

Males excavate a nuptial chamber beneath the bark and eventually mate with one to four females that, in turn, construct egg galleries in the phloem, originating from the nuptial chamber (Christiansen and Bakke 1988). At this time, the host is inoculated with the spores of several blue-stain fungi carried by *I. typographus* (Christiansen and Bakke 1988). Parent females may leave the successfully colonized host and establish another brood in other trees or logs (Christiansen and Bakke 1988).

The number of generations per year is dependent upon temperature. In the northern portion of its range, *I. typographus* is univoltine (Christiansen and Bakke 1988) but can complete two generations per year farther south where degree days above 7 °C exceed 1,250. In the north, beetles emerge from July to October, depending on factors such as time of brood establishment, microclimate, and weather (Christiansen and Bakke 1988). Farther south in Europe, Duelli et al. (1986) described two peak flight periods: May–June for the overwintering populations and July–August for the summer generation. The second generation may emerge in November, but more typically, adults hibernate in the brood tree or forest litter and emerge the following spring (Christiansen and Bakke 1988).

Specific Information Relating to Risk Elements—

A. Likelihood of introduction

1. Presence with host or commodity at origin potential: *High* (*VC*) (Applicable risk criteria: a, b, c, d, e, f, g, h)
The European spruce bark beetle readily infests down host material that contains fresh cambium. In fact, windstorms frequently provide the breeding material for subsequent outbreaks of *I. typographus* (Christiansen and Bakke 1988). If an infested log is cut into boards, the insects can survive in the processed wood as long as some bark is present. Any SWPM made of spruce and containing bark can harbor life stages of the bark beetle. Solid wood packing material made from the other less common hosts would have a lower likelihood of association: moderate for pine and low for larch. If host material of any species is completely free of bark, the potential for the pest to be with the host at origin would be low. The numerous interceptions of *I. typographus* in SWPM at North American ports since 1995 (the beginning of the bark-free requirement) indicate that the host association is strong and that the SWPM pathway continues to be a risky one for bark-inhabiting scolytids.

2. Entry potential: *High* (*VC*) (Applicable risk criteria; a, b, c, d)
If host material containing life stages of the European spruce bark beetle is rapidly processed into SWPM and shipped promptly, there is a high likelihood that live insects will arrive at the destination. *Ips typographus* has been intercepted numerous times in North American ports in association with SWPM. Ports with recent interceptions from dunnage include Erie, PA (1993), Camden, NJ (1994), and Burns Harbor, IN (1995). In total, there were 75 interceptions of *I. typographus* between 1995 and 1998 in association with SWPM entering the United States.

3. Establishment potential: *High* (*RC*) (Applicable risk criteria: b, c, e, f)
Various species of spruce occur throughout North America, including the coastal areas near ports of Alaska, British Columbia, Washington, Oregon, and northern California. Given that *I. typographus* has produced outbreaks in at least two Eurasian spruce species (*P. abies* and *P. jezoensis* [Christiansen and Bakke 1988]), there is reason to be concerned that North American species could also serve as hosts for the bark beetle. *P. jezoensis* is taxonomically similar to *P. sitchensis* and *P. engelmannii*, and has excellent crossability with *P. glauca* (Wright 1955). The species in the genus *Picea* are fairly closely related (J. Alden 1999, personal communication), and little genetic differentiation occurs within the genus (Wright 1955). *Picea sitchensis* growing in Europe has been attacked by *I. typographus*, although this spruce is not a primary host and thus far has not experienced outbreaks (S. Murphy 1999, personal communication). It is important to note that in Norway, trees in other genera have also been killed on occasion by *I. typographus* (E. Christiansen 1999, personal communication). In some parts of the range of *I. typographus*, other hosts are preferred to *Picea* (Krivolutskaya 1983), and thus stands of *Pinus* and *Larix* near North American ports of entry may also be at risk.

4. Spread potential: *High* (*RC*) (Applicable risk criteria: a, b, c, d, e, f, g, h)
The European spruce bark beetle has demonstrated strong dispersal capability (Botterweg 1982), including an extreme case in which *I. typographus* adults were captured on a baited log 43 km from the nearest spruce forest (Nilssen 1984). If local host material were successfully colonized and certain conditions such as drought or windstorms prevailed, the beetle could spread rapidly throughout North American spruce forests, as demonstrated by the numerous severe outbreaks in Europe, where host forests are much more fragmented than in North America (Niemelä and Mattson 1996). The

contiguousness of many North American spruce stands would also favor rapid spread of the insect if it were established.

B. Consequences of introduction

5. Economic damage potential: *High* (*RC*) (Applicable risk criteria: a, b, c, d, f)
Some recent outbreaks in Europe and Scandinavia have resulted in trees being killed over large areas with losses totaling several million cubic meters of wood (Eidmann 1992, Worrell 1983). An epidemic following World War II killed 30 million cubic meters of Norway spruce in central Europe (Schwerdtfeger 1957) over a 7-year period. Some previous outbreaks in German and Norwegian forests have lasted for 30–50 years (Christiansen and Bakke 1988). In Norway, an outbreak in the 1970's that killed 5 million cubic meters of spruce led to a substantial reduction of the country's gross national product (Christiansen and Bakke 1988). Numerous other examples exist throughout Europe and Asia of very large-scale outbreaks of *I. typographus* that have had devastating effects on forest resources (Christiansen and Bakke 1988, Inouye and Yamaguchi 1955). These outbreaks have occurred throughout the entire climatic range of the European spruce host (*P. abies*) and in Japan in the Asian host (*P. jezoensis*). (The Asian host is attacked by a subspecies, *I. typographus* L. f. *japonicus* Niijima).

The bluestain fungus *Ceratocystis polonica* (Siemaszko) Moreau appears to be particularly virulent and is of concern owing to its ability to kill healthy spruce trees. If introduced into North America, the fungus could be transmitted by indigenous bark beetles (*Dendroctonus rufipennis* LeConte, *Ips* spp., etc.) with effects possibly similar to those produced by Dutch elm disease.

The USDA Forest Service conducted an economic analysis for *I. typographus* in the pest risk assessment for importation of larch from the Soviet Far East (USDA Forest Service 1991). That analysis considered forest resources in the Pacific Northwest and estimated the best-case and worst-case scenarios to range between $201 million and $1.5 billion (. $238 million to $1.8 billion in 1998 dollars) in losses in Washington and Oregon caused by the introduction of *I. typographus* into the United States.

Control of *I. typographus* relies on many of the same techniques that are applied to native bark beetles. The approaches involve either the manipulation of habitat or direct reduction of beetle populations. One of these approaches is the avoidance of population buildups by limiting the amount of host material available to the bark beetle. Prompt salvage or debarking of windthrown material may help to limit population growth but may be impractical when large areas are involved. Direct controls have included the use of attractant and repellent pheromones either to trap out beetles or reduce attacks on suitable host material. Insecticides have also been used in direct control but have several limitations in their application. It is important to note that outbreaks of *I. typographus* and native bark beetles continue to occur in Eurasia and North America, respectively, despite all of the control strategies that are employed.

6. Environmental damage potential: *High* (*RC*) (Applicable risk criteria: a, c, d)
Introduction of the Eurasian spruce bark beetle into the United States could threaten the ecological position of Sitka and Engelmann spruces in mixed-species forests in favor of associated species such as western hemlock, the true firs, mountain hemlock, and lodgepole pine. The introduction of associated virulent fungi such as *Ceratocystis polonica* (Siemaszko) Moreau could cause additional disruption in the environment by damaging the spruces.

7. Social and political considerations: *High* (*MC*) (Applicable risk criteria: a, c)
The spruces, including Norway spruce, are important ornamental species in northern North America. As urban trees, they have even greater value than the wood they contain. The introduction of *I. typographus* could threaten this urban resource and lead to greater pesticide usage by homeowners.

C. Pest risk potential: **High** (Likelihood of introduction = *High*; Consequences of introduction = *High*).

Mediterranean Pine Engraver Beetle

Assessor—Andris Eglitis

Scientific Name of Pest—*Orthotomicus erosus* Wollaston (Coleoptera: Scolytidae)

Scientific Names of Hosts—*Pinus* spp. including *P. armandii* Franch, *P. brutia* (Ten.) , *P. canariensis* C. Smith, *P. caribaea* Morelet, *P. coulteri* D. Don, *P. echinata* Mill., *P. eldarica* Medw., *P. elliottii* Engelm., *P. halepensis* Mill., *P. khasya* Royle, *P. leucodermis* Ant., *P. maritima* Poir., *P. massoniana* Lamb., *P. nigra* Arnold, *P. nigricans* Host., *P. pallasiana* D. Don, *P. patula* Schiede & Dieppe, *P. pinaster* Ait., *P. pinea* L., *P. pithyusa* Stev., *P. radiata* D. Don, *P. strobus* L., *P. sylvestris* L., *P. tabulaeformis* Carr., *P. uncinata* Mirb., *P. yunnanensis* Franch; occasionally *Pseudotsuga menziesii* (Mirbel) Franco, *Picea* spp., *Abies* spp., *Cedrus* spp., primarily for maturation feeding.

Distribution—Mediterranean region including Portugal, Spain, France, Switzerland, Italy, Bulgaria, Romania, Greece, Iran, Turkey, Israel, Jordan, Syria, Egypt, Libya, Tunisia, Algeria, Morocco; eleven provinces in China. Introduced into England (1921), Tadzhikistan, Republic of South Africa (1976), Fiji (1985), and Chile (1986). There is some uncertainty about the distribution within Europe with conflicting reports about occurrence of *O. erosus* in Latvia, Germany, Austria, Poland, and the Scandinavian countries.

Summary of Natural History and Basic Biology of the Pest—*Orthotomicus erosus* is a secondary bark beetle that normally infests recently fallen trees, broken branches, slash, and standing trees that have been wounded or are under some form of stress (Mendel and Halperin 1982, Chararas and M'Sadda 1973). In Morocco, Questienne (1979) noted that bark beetles affected pine plantations more heavily than natural stands because of less than optimum climatic and edaphic conditions in the plantations. Baylis et al. (1986) reported attacks of *O. erosus* on fire-damaged pines of various species (*P. radiata*, *P. elliottii*, *P. pinaster*) in South Africa. Moisture deficiency is one of the key factors leading to attack by the Mediterranean engraver beetle. Bevan (1984) noted that *O. erosus* was normally secondary in plantations of *P. patula* and *P. elliottii* in Swaziland but would attack live trees under extreme drought stress. Serrao-Nogueira (1976) referred to trees weakened in urban settings by lack of water and then infested by *O. erosus*. In Italy, Capretti et al. (1987) described *O. erosus* damage in 12- to 20-year-old *P. halepensis* plantations following a hot dry summer and very cold winter. Sometimes other insects or diseases are the stressing agents that lead to attacks by *O. erosus*. In France, Carle (1971) noted that *O. erosus* was one of the beetles involved in the decline of *P. pinaster* following weakening of the host by *Matsucoccus feytaudi* Duc. scale insects. Zwolinski et al. (1995), working in the Republic of South Africa, described the incidence of *O. erosus* on *P. radiata* trees infected with *Sphaeropsis sapinea* (Fr.) Dyko & Sutton [= *Diplodia pinea* (Desm.) Kickx.]. *Orthotomicus erosus* was one of two beetles attacking these trees and was confined to the zone of discoloration produced by the fungus.

Throughout its range, there have been reports of population buildups of *O. erosus* in its typical host material followed by attacks on healthy trees. In Israel, Halperin et al. (1982) linked the increase of bark beetle outbreaks in *P. halepensis* to maturation of plantations and an increase in thinnings. Also in Israel, Mendel and Halperin (1982) reported that the agents predisposing stands to attack were thinnings followed by winters of low rainfall or fires in neighboring pine stands. Ferreira and Ferreira (1986) pointed out that *O. erosus* has periodically reached epidemic numbers and has caused the death of many *P. pinaster* trees in Portugal.

Orthotomicus erosus infests a wide variety of pines, which are essentially the only true hosts in which the beetle can reproduce (Mendel and Halperin 1982). References to other hosts such as *Cedrus* spp. and *Abies* spp. are rare and usually refer to adult aggregations for hibernation or maturation feeding. The beetle generally breeds in the rough-barked sections of the main trunk and in branches larger than 5 cm in diameter. (Smooth-barked areas are used, but primarily for maturation feeding.) The lower trunk of relatively old pines is not suitable because the bark is too thick. In Israel, trees younger than 5 years old are usually not attacked (Mendel and Halperin 1982). *O. erosus* commonly occurs in association with other bark beetles. Common associates on pines in Israel included *Pityogenes* *calcaratus* Eichhoff, *Tomicus destruens* (Wollaston), and *Carphoborus minimus* F. (Mendel and Halperin 1982). In South Africa, Tribe (1990) found *Hylastes angustatus* (Herbst), *Hylurgus ligniperda* (Fab.) and *Pissodes nemorensis* Germar associated with *O. erosus*.

Males initiate attacks on suitable host material by boring through the bark to the phloem–cambium layer where they construct a nuptial chamber. The males are joined by one to three females, each of which mates with the male and then constructs an individual egg gallery from the nuptial chamber parallel to the grain of the wood. Each female typically lays between 26 and 75 eggs in niches along the sides of the galleries (Mendel and Halperin 1982). Females will make "ventilation holes" in their egg galleries and will sometimes abandon the gallery and finish their egg-laying in another host. The larvae mine at right angles to the parent gallery and pass through three instars during their development. The adults must feed before reaching their sexual maturation. This feeding occurs beneath the bark of the brood host (if the bark is still moist) or in another host—sometimes of a different conifer species. On occasion, the maturation feeding will take place during the normal egg-gallery construction and oviposition (Mendel and Halperin 1982).

O. erosus is associated with several important fungi. Wingfield and Marasas (1980) described the association of *O. erosus* with *Ophiostoma* (= *Ceratocystis*) *ips* (Rumbold) Nannf., a pathogenic fungus in *P. pinaster* and *P. radiata* in South Africa. They also discussed the association of this bark beetle with *Verticicadiella alacris* Wingf. & Marasas [= *Leptographium serpens* (Goid.) Siemaszko*; = Ophiostoma serpens* (Goid.) von Arx] in pines that together with other beetles and fungi, form a pest complex producing losses in pine plantations.

The Mediterranean pine engraver completes two to seven generations per year, depending on temperature. Two generations per year are common in Turkey, France, and Morocco. In Tunisia, Chararas and M'Sadda (1973) found that *O. erosus* completed three and sometimes four generations in a year and that development time was a function of the nutritive quality of the phloem as well as temperature. In Israel, where the beetle can complete three to five generations in a year, the time required for development of a brood varies from 25 days in the summer to 76 days in the winter (Mendel 1983). On the basis of these development times, Mendel (1983) concluded that coastal Israel could have as many as seven generations per year. Tribe (1990) estimated four generations per year in South Africa given an average development time of 35 days for one generation. The winter is spent in the adult stage as the beetles aggregate beneath the bark of the host in which they developed or in a new one. The beetles enter the host through a single hole and then concentrate as many as several hundred individuals in the phloem–cambium region (Mendel 1983). This aggregation occurs between mid-October and December. Beetle flight can occur through a broad temperature range of 14 to 38 °C (Chararas and M'Sadda 1973). In Israel, the threshold for flight is even lower during winter (12 °C) (Mendel 1983).

Specific Information Relating to Risk Elements—

A. Likelihood of introduction

1. Presence with host or commodity at origin potential: *High* (*VC*) (Applicable risk criteria: a, c, d, e, f, g, h)
   O. erosus is commonly associated with recently dead host material (Mendel and Halperin 1982). A broad host range in pines and multiple generations in much of this beetle's range leads to a high likelihood of its being associated with crating material if the wood contains bark. Numerous interceptions in U.S. ports since the ban of bark from SWPM, recorded under the old taxonomic combination *Ips erosus,* indicates that this association is still commonly occurring.

2. Entry potential: *High* (*VC*) (Applicable risk criteria: a, b, c, d)
   From 1985 to 1996, *O. erosus* was the second most commonly intercepted bark beetle at U.S. ports. During that time it was intercepted 340 times from 19 different countries. Between 1995 and 1998 (after the regulations for bark-free SWPM were put into effect), there were 28 interceptions of *Orthotomicus*

spp. at U.S. borders in association with SWPM. (Ten of these interceptions were identified as species other than *O. erosus*, and *O. erosus* was not specifically recorded). Another 57 interception records refer to *Ips erosus*, a previously used combination for *Orthotomicus erosus*. The host association and transportability of *O. erosus* is strongly demonstrated by the observations of Schroeder (1990), who reported that six shipments of *Pinus pinaster* logs imported into Sweden from France all contained live larvae and adults of the engraver beneath the bark. Siitonen (1990) reported that *O. erosus* was found in Russian logs (*Pinus sylvestris* and some other conifer genera, including *Larix* and *Picea)* sent to Finland—a distance of over 5,000 km.

3. Establishment potential: *High* (*MC*) (Applicable risk criteria: a, b, c, d, e, f)
Orthotomicus erosus has a broad host range that covers many species within the genus *Pinus*. Its successful introduction into five other countries shows adaptability to new hosts within the genus *Pinus*. Chararas (1973) reported that in Turkey, *O. erosus* was raised on a variety of hosts, including American pines. In that study, *O. erosus* was little affected by the differences in host terpenes provided that they did not differ drastically from the original or did not contain repellants such as heptane (found in *Pinus jeffreyii*). Although obviously adaptable, the competitive ability of *O. erosus* may be another matter. In Chile, this beetle was introduced in 1986 but was not successful in competing with *Hylurgus ligniperda* (Fab.) for the same ecological niche and is now difficult to find in that country. However, Karnavar (1984) reported that *O. erosus* first appeared in Swaziland (RSA) in the early 1980's and soon became a major pest.

4. Spread potential: *High* (*MC*) (Applicable risk criteria: a, b, c, d, e, f, g, h)
The broad host range would favor the spread of *O. erosus* within pine-growing regions. However, the beetle appears to require its host to be stressed in order to be successful in live trees. A Mediterranean climate is also most appropriate for this insect. As such, *O. erosus* could be successful in areas such as Santa Cruz and Monterey, CA, where one of its hosts, *P. radiata,* is already being challenged by the recently introduced pitch canker caused by the fungus *Fusarium circinatum* Nirenberg and O'Donnell [= *F. subglutinans* (Wollenw. and Reinking) Nelson et al. f. sp. *pini* Correll et al.]. The beetle is well adapted to the hot conditions such as those in Israel (Mendel and Halperin 1982), which may make it successful in other climates as well. Although the flight capability of the insect has not been documented, the beetle has often spread successfully once introduced into new environments.

B. Consequences of introduction

5. Economic damage potential: *High* (*MC*) (Applicable risk criteria: a, b, c, d, f)
O. erosus has caused damage in some parts of its natural range and in some areas of introduction. Its greatest significance would be in areas where plantations have been established under conditions that are not always favorable and in natural forests where drought and other stress factors are common. Some of the damage caused by *O. erosus* has involved pathogenic fungi (Wingfield and Marasas 1980). Although some of these fungi already occur in the United States, there may be other associated disease-causing fungi that have not been reported and could elevate the impact this insect could have. The controls for *O. erosus* are fairly standard and primarily involve clean forest practices whereby slash and other potential habitats are regulated to avoid population buildups.

6. Environmental damage potential: *High* (R*U*) (Applicable risk criteria: c, d)
The native pine forests in the United States have numerous species from the genus *Ips* and one species of *Orthotomicus* that behave in a similar manner to *O. erosus*, colonizing slash, windthrows, and weakened trees and, under certain conditions, spreading to healthy trees. Introduction of *O. erosus* into ecosystems containing pines could lead to the displacement of native bark beetles that occupy the same niche as *O. erosus.* Numerous fungi are associated with the Mediterranean pine engraver (Wingfield and Marasas 1980), some of which already occur in the United States as well as others that may not have been

identified. The introduction of the latter fungi could have disruptive effects in pine ecosystems either as mortality agents or as organisms that compete with and displace native organisms.

7. Social and political considerations: *Low* (*RC*) (Applicable risk criteria: none)

C. Pest risk potential: **High** (Likelihood of introduction = *High*; Consequences of introduction = *High*).

European Oak Bark Beetle

Assessor—Robert A. Haack

Scientific Name of Pest—*Scolytus intricatus* (Ratzeburg) (Coleoptera: Scolytidae)

Scientific Names of Hosts—Breeding occurs primarily in species of oak (*Quercus*) (Duffy 1953b, Wood and Bright 1992). In addition, species of *Aesculus*, *Betula*, *Carpinus*, *Castanea*, *Corylus*, *Fagus*, *Ostrya*, *Populus*, *Salix*, *Sorbus*, and *Ulmus* have been listed as occasional hosts in the literature (Duffy 1953b, Lekander et al. 1977, Schedl 1981, Schwenke 1974). Upon emergence, new adults typically shoot-feed for a few days or weeks, utilizing oaks primarily (Doganlar and Schopf 1984, Yates 1984). In laboratory tests, *Scolytus intricatus* adults shoot-fed on species of *Aesculus*, *Alnus*, *Betula*, *Carpinus*, *Castanea*, *Eleagnus*, *Fagus*, *Juglans*, *Liquidambar*, *Morus*, *Prunus*, *Quercus*, *Salix*, and *Ulmus* (Doganlar and Schopf 1984).

Distribution—Africa: Morocco and Tunisia. Asia: Turkey. Europe: Austria, Belgium, Bulgaria, the Czech Republic, Denmark, England, Finland, France, Germany, Greece, Hungary, Italy, Luxembourg, the Netherlands, Norway, Poland, Romania, Scotland, Slovakia, Spain, Sweden, Switzerland, western portion of the former USSR, and the former Yugoslavia (Crowson 1962, Wood and Bright 1992). Lekander et al. (1977) reported the range of *S. intricatus* as the whole of Europe and north Africa. Schwenke (1974) described the eastern range of *S. intricatus* as extending to the Caucasus Mountains and northern Iran. Schedl (1981) described the distribution of *S. intricatus* as following the range of oak in Europe and Asia Minor. *Scolytus intricatus* has been reported in Azerbaijan (Guseinov 1984). Detailed maps of the range of *S. intricatus* in Scandinavia are given by Heliövaara et al. (1991) and Lekander et al. (1977).

Summary of Natural History and Basic Biology of the Pests—*Scolytus intricatus* is a typical bark beetle, completing four life stages: egg, larva, pupa, and adult. Adults measure 2.4 to 4.0 mm in length (Duffy 1953b, Kamp 1951, Munro 1926, Schedl 1981, Schwenke 1974, Yates 1984). Except when adults are seeking new host material for breeding or shoots for maturation feeding, all life stages occur under bark within the cambial region. In England, *S. intricatus* completes one generation per year (Yates 1984), whereas two generations per year are completed in southern Germany (Kamp 1951). *Scolytus intricatus* typically overwinters in the late larval stages (Lekander et al. 1977, Yates 1984), or occasionally in the pupal stage (Doganlar and Schopf 1984). Overwintering and subsequent pupation usually take place in the outer bark if the bark is over 4 mm thick or in the outer sapwood if the bark is thinner (Lekander et al. 1977, Yates 1984). Pupation usually occurs in late spring or early summer and lasts for 1 to 2 weeks (Yates 1984). In England, adult emergence usually spans 2–3 weeks and, depending on local temperatures, occurs from mid-May through late June (Yates 1984). *Scolytus intricatus* has a 1:1 sex ratio at the time of adult emergence (Doganlar and Schopf 1984, Yates 1984).

Upon emergence, adults fly to the crowns of trees, primarily oaks, and conduct maturation feeding on the twigs, usually at the juncture of current-year and 1-year-old growth (Lekander et al. 1977, Munro 1926, Yates 1984). This maturation twig-feeding by *S. intricatus* adults is similar to that conducted by newly emerged *Scolytus multistriatus* (Marsham) adults, which is the principal method by which the *S. multistriatus* transmits the causal agents of Dutch elm disease (Sinclair and Campana 1978). In England, the period of *Scolytus intricatus* shoot feeding was estimated at 2–3 weeks given that this was the difference in time between peak adult emergence and peak attack on brood material (Yates 1984). As mentioned above, Doganlar and Schopf (1984) found that *S. intricatus* adults preferred to shoot-feed on *Quercus* but would also accept species of *Aesculus*, *Alnus*, *Betula*, *Carpinus*, *Castanea*, *Eleagnus*, *Fagus*, *Juglans*, *Liquidambar*, *Morus*, *Prunus*, *Salix*, and *Ulmus* in laboratory tests. In addition, in laboratory tests, Doganlar and Schopf (1984) noted that shoot-feeding did not occur on species of *Acer*, *Celtis*, *Crataegus*, *Fraxinus*, *Liriodendron*, *Populus*, and *Sambucus*. It should be noted that shoot-feeding is not obligatory given that newly emerged adults will reproduce if placed directly on freshly cut logs (Doganlar and Schopf 1984, Habermann and Schopf 1987, Yates 1984).

After shoot-feeding, adults seek breeding sites, which are usually the trunks and branches (> 5 cm in diameter) of weakened and dying oaks as well as recently fallen branches (Gibbs 1978b; Lekander et al. 1977; Yates 1981, 1984). In the laboratory, *S. intricatus* successfully constructed egg galleries in branches that were only 1 to 1.5 cm in diameter (Doganlar and Schopf 1984). *Scolytus intricatus* has been reported to breed in oak trees stressed by drought (Eisenhauer 1989, Gibbs 1978b, Novak 1988, Yates 1984), air pollution (Krol 1982), and insect defoliation (Eisenhauer 1989, Szontagh 1984, 1985). In addition, *S. intricatus* will breed in branches cut 12–18 months earlier (Yates 1984). The pheromone system of *S. intricatus* has not been completely determined, but Yates (1984) suggests that males may produce aggregation pheromones, and research in the laboratory of W. Francke (Hamburg, Germany) has revealed that *S. intricatus* produces several compounds typical of the Scolytidae (S.J. Seybold, personal communication). Mating may occur on twigs during maturation feeding (Doganlar and Schopf 1984) or later during gallery formation (Yates 1984). Adult flight may be limited to less than 100 m (Edel'man and Malyseva 1959). Depending on the location and the number of generations per year, adult activity usually occurs between May and September (Doganlar and Schopf 1984; Lekander et al. 1977; Yates 1981, 1984). There is little evidence that reemergence of parent adults occurs (Yates 1984).

Scolytus intricatus is monogamous. Either the male or female can initiate construction of the egg gallery (Yates 1984). Egg galleries are constructed perpendicularly to the wood grain (i.e., transverse). Eggs are laid individually in niches constructed along both sides of the egg galleries. On average, egg galleries are about 11 mm long and range from 5 to 20 mm (Chapman 1870, Yates 1984). Average egg batch size was reported to range between 18 and 36 eggs per gallery in studies conducted in England (Yates 1984). However, in Germany, average batch sizes of 36 to 83 eggs were reported (Doganlar and Schopf 1984). Adult females typically lay eggs over a 2-week period and then die—usually within their egg galleries (Yates 1984).

Egg hatch typically occurs in 10 to 14 days (Yates 1984). There are five larval instars (Yates 1984), or possibly six (Doganlar 1984). The larval galleries tend to orient vertically, with the grain of the wood, and can extend up to 10 cm (Yates 1984) or even 15 cm (Chapman 1870).

Several natural enemies of *S. intricatus* have been reported in the literature, including parasitic wasps (Capek 1986, Markovic and Stojanovic 1996, Pettersen 1976, Zach 1994) and woodpeckers (Pavlik 1994).

Scolytus intricatus has been associated with oak decline throughout its native range (Kolk 1985, Markovic and Stojanovic 1996, Novak 1988, Pavlik 1994, Rossnev et al. 1994, Szontagh 1984, Zach 1994). In a few studies, *S. intricatus* adults were found to be contaminated with *Ophiostoma* fungal spores at the time of emergence from their brood tree (Edel'man and Malyseva 1959, Guseinov 1984, Struka 1996). In other studies, *S. intricatus* was implicated as the principal vector of the various fungi associated with oak decline in Europe (Eisenhauer 1989, Guseinov 1981, Kolk 1985, Kryukova 1976, Rossnev et al. 1994). Given the preceding information, many authors consider that *S. intricatus* would be a very effective vector of the oak wilt fungus, *Ceratocystis fagacearum* (Bretz) Hunt, if either the beetle became established in the United States or if the fungus became established in Europe (Doganlar et al. 1984, Doganlar and Schopf 1984, Gibbs 1978b, Gibbs and French 1980, Schopf et al. 1984, Yates 1984).

Specific Information Relating to Risk Elements—

A. Likelihood of introduction

1. Presence with host or commodity at origin potential: *High* (*VC*) (Applicable risk criteria: a, c, d, e, f, g, h)
Scolytus intricatus is known to colonize recently dead and dying hardwood host trees, primarily oaks, throughout its native range. Therefore, *S. intricatus* adults will readily colonize trunks and branches of suitable host trees that are available during their summer flight period. Because all life stages of this bark beetle can be found under bark, SWPM with bark attached could harbor *S. intricatus* life stages for

about 1 year following initial infestation.

2. Entry potential: *High* (*VC*) (Applicable risk criteria: a, b, c, d)
According to a query of the USDA APHIS Port Interception Network (PIN–309) data base, *S. intricatus* was intercepted at United States ports of entry on 12 occasions from 1985 through late 1998, making it the 20th most commonly intercepted scolytid at U.S. ports. Five of the 12 interceptions were made on cargo that originated from Belgium, 4 were from France, 1 from Germany, 1 from Italy, and 1 had an unknown origin. In addition, on 63 occasions during 1985–98, *Scolytus* spp. bark beetles were intercepted and identified to only the genus level: Belgium—25 interceptions, Belize—2, Brazil—1, China—6, Finland—1, France—2, Germany—2, Japan—1, Italy—4, India—1, Mexico—1, the Netherlands—1, Russia—4, Spain—1, unknown—6, United Kingdom—3, and Venezuela—1. The 12 *S. intricatus* interceptions were associated primarily with dunnage and crating. A similar trend was found for the wood products associated with the 63 *Scolytus* sp. interceptions, but in addition to dunnage and crating, beetles were also found on pallets, lumber, and inside live host material (PIN–309 data base). Given the preceding information, it is certain that *S. intricatus* can successfully survive oceanic transit to the United States.

3. Establishment potential: *High* (*RC*) (Applicable risk criteria: b, c, e, f)
Scolytus intricatus utilizes primarily oak trees for shoot-feeding and breeding, although several other genera of hardwood trees serve as occasional hosts. In the United States there are 58 species of oak that reach tree size and another 10 species that are considered shrubs. Oaks are found in each of the 48 contiguous states. Therefore, *S. intricatus* would encounter suitable host trees near most ports of entry throughout the continental United States. Moreover, given that *S. intricatus* can colonize and breed in trunks and branches of host trees for up to 12–18 months after cutting, it is very likely that *S. intricatus* would easily find suitable host material for breeding upon entry to the United States. Given that the range of *S. intricatus* extends from northern Africa to Scandinavia, it is very likely that *S. intricatus* could survive the climatic extremes found throughout the continental United States.

4. Spread potential: *High* (*RC*) (Applicable risk criteria: a, c, d, e, f, g, h)
Scolytus intricatus has the potential to spread throughout the contiguous 48 states given that at least one species of oak is native to each State except for Alaska and Hawaii. Although adult flight is generally less than 100 m, adults can easily be moved longer distances by wind and through human transport of infested host material, particularly in oak firewood, which is highly preferred for heating.

B. Consequences of introduction

5. Economic damage potential: *High* (*MC*) (Applicable risk criteria: a, b, c, d, f)
If *S. intricatus* were only to colonize trunks and branches of trees that had recently died or been cut, then there would be relatively little economic impact. However, because *S. intricatus* can attack and kill stressed oaks in its native range, it would likely behave similarly if introduced into the United States. Currently in the United States, the buprestid beetle *Agrilus bilineatus* (Weber) and various species of *Armillaria* root-rotting fungi are the major mortality agents of stressed oaks (Haack and Acciavatti 1992, Wargo and Haack 1991). It is possible that *Scolytus intricatus* could act synergistically with *Agrilus bilineatus* and *Armillaria* spp. to cause even higher levels of oak mortality during periods of environmental stress.

The major concern with *Scolytus intricatus*, however, is that it is likely to serve as an efficient vector of the oak wilt fungus, in a way that parallels the activity of *Scolytus multistriatus* (Marsham) as an efficient vector of the Dutch elm disease fungi *Ophiostoma ulmi* (Buism.) Nannf. and *Ophiostoma novo-ulmi* Brasier (Sinclair and Campana 1978). Oak wilt, which occurs in the Eastern United States, is now transmitted primarily by native sap beetles in the family Nitidulidae and to a lesser degree by the native branch- and twig-infesting bark beetles in the genus *Pseudopityophthorus*. Because *Scolytus intricatus* is known to carry the spores of other wilt disease pathogens in Europe, it is possible that it could also transmit the oak wilt fungus. If *S. intricatus* were to spread the oak wilt fungus as efficiently as *Scolytus multistriatus* does for the Dutch elm disease fungi, then the potential losses to the oak resource of the United States would be great. Oaks are common trees in cities, yards, parks, campgrounds, and forests throughout the United States. If oak wilt reached outbreak levels, huge dollar amounts would have to be spent by governments and private citizens on tree removal and replanting efforts. In general, effective control methods are lacking for insects such as *S. intricatus*, especially in forest stands.

6. Environmental damage potential: *High* (*MC*) (Applicable risk criteria: a, c, d, e)
   As stated above, if *S. intricatus* were only to colonize recently dead host material, then there would be relatively little environmental damage. However, given that *S. intricatus* will attack and kill drought-stressed oaks and is likely to be an efficient vector of the oak wilt fungus, the potential environmental damage that would result from its introduction would be great. Because oaks (a) are the dominant tree species in many forest types throughout the United States, and (b) provide food and shelter to numerous wildlife species, including several game species, any sudden decline in oak coverage would have major impacts on ecosystem stabilization and biodiversity.

7. Social and political considerations: *High* (*MC*) (Applicable risk criteria: a, b, c, d)
   If *S. intricatus* were only to colonize recently dead and dying oaks, the perceived damage would be low. However, because *S. intricatus* will likely attack and kill stressed oaks and transmit the oak wilt fungus if introduced into the United States, the resulting tree losses in urban and rural landscapes would be widespread. High levels of oak mortality and the resulting costs of tree removal would severely impact all levels of government and the public. Because of their potential hazard to people and property, dead oak trees would have to be removed along streets and in parks, yards, campgrounds, and so forth. The social, political, and economic costs involved in a large-scale oak removal program, if oak wilt were to become widespread, would certainly rival the costs associated with Dutch elm disease.

C. Pest risk potential: **High** (Likelihood of introduction = *High*; Consequences of introduction = *High*).

Defoliators

Gypsy Moth (Asian Biotype)

Assessor—William E. Wallner

Scientific Name of Pest—*Lymantria dispar* L. (Lepidoptera: Lymantriidae)

Scientific Names of Hosts—The Asian biotype of gypsy moth has more than 500 host species but prefers species of *Betula*, *Larix*, *Malus*, *Populus*, *Quercus*, and *Salix*. Although hardwoods are preferred hosts, conifers may be defoliated during periods of high insect densities (Baranchikov 1989, Barbosa and Greenblat 1979).

Distribution—Although the gypsy moth's distribution is gradually expanding because of human activities, it is largely a temperate forest pest. It is found in Eurasia within latitudes 20°–60°N. (Montgomery and Wallner 1988, Sun 1989, Grijpma 1989).

Summary of natural history and basic biology of the pest—The Asian biotype of the gypsy moth, even though it belongs to the same species as the European gypsy moth, is genetically distinct enough to merit separate consideration of regulatory treatment. Although the biological characteristics are similar in most respects, females of the Asian biotype (and hybrids containing Asian heritage) have the ability to fly, whereas females of the purely European biotype do not fly. This results in differences in spread potential. The Asian biotype has been introduced into North America several times but populations were eradicated, and the Asian biotype is not known to occur currently in North America unlike the European biotype, which infests much of the Northeastern United States.

The gypsy moth is an episodic, univoltine defoliator that erupts into defoliating densities for 1 to 3 years and subsides for an indeterminate period of years. In temperate environments, masses of eggs (500 to 1,000) pass the winter on or under tree bark, rocks, fallen branches, or manmade objects (signs, litter, etc.) (Campbell et al. 1975). One generation appears each year, and hatching occurs from April to late May, depending upon location and weather, though egg hatching usually coincides with budbreak of most hardwood trees (Leonard 1981). Larvae hatching from these eggs balloon on silken threads and disperse until they encounter a suitable host, where they initiate feeding. During the next 1–1½ months, they pass through five to six instars, feeding during the evening on the foliage and migrating to rest in protected locations during the day. Pupation occurs in these resting locations, although at outbreak densities pupation occurs in less protected sites; adults emerge in about 2 weeks, mate, and lay their eggs (Campbell et al. 1975).

Egg masses are a resilient, easily transported life stage often affixed to pallets and wood packing materials as well as shipping containers, vehicles, ships, and so forth. Because the egg stage lasts about 9 months, it has provided a pathway for long-distance dispersal. Larvae hatching from these eggs rarely disperse more than several hundred meters (Mason and McManus 1981). Mature larvae account for only short-distance movement. Larval and human-mediated movement account for the redistribution of the European gypsy moth (whose females, although winged, are incapable of flight). The Asian gypsy moth is a strong flier capable of sustained flight of . 20–25 km. Readily attracted to artificial lights, where they deposit their egg masses, females have been responsible for recent introductions into the United States, Canada, and Western Europe (Wallner et al. 1995).

Egg masses are ovoid—4–5 cm in length and 2–3 cm in width—and contain 100-1,000 eggs covered in buff-brown hairs from the female's abdomen. Newly hatched larvae are 3 mm long and tan, but after 24 hours turn black. Once feeding is initiated, larvae proceed through five instars for males and six instars for females and reach a length of 50–90 mm with two rows of dorsal blue and red spots. In sparse populations, feeding may hardly be noticeable and larvae hard to locate because they prefer to rest in dark locations such as under bark flaps, stones, and litter on the ground. However, in dense, defoliating populations, larvae will feed continuously, and their frass droppings have the sound of rain.

The adult male is mottled brown with black markings. The female is white or cream with distinctive black marking on the wings. By emitting a pheromone, the female attracts males for mating. The principal means to detect new or sparse populations is to use disparlure, a synthetic pheromone, in traps (Cardé et al. 1978; Hansen 1984). Burlap bands placed around the boles of host trees will attract larvae and may be useful in detecting larvae at low densities (Wallner et al. 1989). Frass traps also have been employed (Liebhold and Elkinton 1988). Because they are labor-intensive, these techniques receive limited use for initially detecting new invasions.

Taxonomic identification of specimen material is possible (Ferguson 1978), and comparisons with other Lymantriid species can be made (Schaefer 1989). However, these traditional methods are incapable of identifying geographical biotypes of gypsy moth. For this purpose, several techniques can be used: mitochondrial DNA sequencing (Bogdanowicz et al. 1993), RAPD–PCR markers (i.e., Random Amplified Polymorphic DNA–Polymerase Chain Reaction) (Garner and Slavicek 1996), or microsatellite DNA variation (Bogdanowicz et al. 1997). A combination of these techniques may be necessary when identifying Asian–North American hybrids.

The gypsy moth life system is complex, and density is influenced by many interacting factors. Vertebrate predators are important in maintaining low densities, parasites often are abundant during outbreak, and pathogens, especially the nucleopolyhedrosis virus, are responsible for collapse of dense populations. Another important natural control is the introduced fungal pathogen, *Entomophaga maimaiga* (Humber, Shimazu et Soper), which is not dependent on gypsy moth density. With the exception of *E. maimaiga*, no natural control has been proven to have sustained suppressive effects on population densities. Chemicals and biopesticides, including insect growth regulators, are routinely used for controlling the gypsy moth in Eurasia and North America.

Specific Information Relating to Risk Elements—

A. Likelihood of introduction

1. Presence with host or commodity at origin: *High* (*RC*) (Applicable risk criteria: a, b, c, d, e, f, g, h)
   The gypsy moth has been reported as feeding on a variety of host types commonly used in SWPM. Given its worldwide distribution, especially in countries with emerging economies, egg masses can readily be transported as hitchhikers on the bark and sawed wood (USDA 1991). Numerous APHIS interception records attest to this pathway. The very resilient (6- to 9-month viability) and difficult-to-detect egg masses can find their way around the globe via trade utilizing wood as a medium of transport.

2. Entry potential: *High* (*RC*) (Applicable risk criteria: a, b, c, d)
   Previous introductions of the gypsy moth are evidence that it should be considered a high quarantine risk. Egg masses are perceived to be the major threat of introduction because the resilient life stage remains viable for up to 9 months. The egg masses are obscure because they are often laid in cracks or crevices in the bark or wood and thus are difficult to detect. The widespread distribution of this insect makes it a virtual certainty that an outbreak is occurring annually somewhere (Montgomery and Wallner 1988), and the potential for infesting pallets and wood packing is an annual threat.

   The Asian gypsy moth is acknowledged to be more threatening than the European biotype, and routine monitoring at ports of entry and rapid response to eliminate new introductions is being undertaken. Both biotypes are prohibited in Canada, Mexico, and the United States, and movement of nursery stock, Christmas trees, household goods, and vehicles from infested to uninfested regions is regulated. The greatest threat of new introductions is via international trade, for packing materials, containers, and vehicles are most often infested (Wallner 1997). Coordination of quarantine activities by North American trading partners, including preentry clearance, notification of infested articles and vessels, and the establishment of time frames for high-risk foreign vessel visitation have heightened security against this pest.

3. Establishment potential: *High* (*VC*) (Applicable risk criteria: a, b, c, d, e, f)
The Asian gypsy moth biotype has consistently demonstrated its potential to get around (Wallner 1997). Its highly polyphagous habits ensure that there would be a high likelihood of encountering acceptable hosts in most North American regions (Baranchikov 1989). Mobile adults and larvae would permit dispersal and redispersal episodes, thus increasing acceptable host finding.

4. Spread potential: *High* (*VC*) (Applicable risk criteria: a, b, c, d, e, g)
Following establishment, populations would expand relentlessly, as has been the case with the gypsy moth European biotype, which spreads at a rate of about 12 km per year (USDA Forest Service and APHIS 1995). In fact, dispersion of Asian gypsy moth populations would be even faster owing to the flight capability of females. The extremely broad range of more than 500 host plant species (Barbosa and Greenblat 1979) would facilitate eventual distribution throughout most of North America.

B. Consequences of introduction

5. Economic damage potential: *High* (*VC*) (Applicable risk criteria: a, b, c, d, e)
Larval defoliation severely weakens and reduces growth of trees, making them susceptible to attack by other insects and pathogens. Mortality of preferred hosts (principally oaks) can shift species composition of forests thus increasing their resistance to future defoliation (Campbell and Sloan 1977). The European gypsy moth biotype has a notorious reputation, and its Asian cousin, with its more aggressive behavior traits, would be even more threatening.

   Annual expenditures for control of the European gypsy moth, which is considered the most costly of introduced forest insect pests, have exceeded $35 million since 1980 (Wallner 1996a). This does not include losses in timber, recreation, and real estate values or disruption to forest ecosystems. For example, in 1981, some 6 million ha of mixed hardwood forests were defoliated in the United States. In Pennsylvania alone, timber loss was estimated to be in excess of $72 million (. $85 million in 1998 dollars), and more than $9 million (. $11 million in 1998 dollars) was expended for spray programs (Gottschalk 1990). Recent efforts to eradicate introduced Asian gypsy moth populations in North America have been undertaken at a cost of more than $25 million (Wallner 1996b).

6. Environmental damage potential: *High* (*RC*) (Applicable risk criteria: a, d, e, f)
The capacity to colonize new environments has consistently been demonstrated by the European gypsy moth. It is anticipated that the Asian gypsy moth, with its vagile females and broader host preferences, will spread more rapidly and more aggressively colonize a variety of habitats (and especially larch forests) that can be found in North America. Negative impacts upon tree growth and mortality can be expected, as has been the experience with the European gypsy moth. However, the behavioral and physiological traits of the Asian gypsy moth will necessitate developing and adopting new techniques and management strategies at additional costs. Defoliation by the European gypsy moth has altered the composition of eastern forests, and the Asian gypsy moth can be expected to exacerbate the problem there. Perhaps the highest risk is to Western North American forests where larch, Douglas-fir, and a variety of oak forests abound (USDA Forest Service 1991).

   Chemical and biological sprays can reduce the impact of defoliation but are used with attendant risks to nontarget organisms and disruption of ecosystems (USDA Forest Service and APHIS 1995). Parasites, predators, and diseases that control the European gypsy moth are anticipated to be operative against the Asian gypsy moth. However, the scale of the detection, monitoring, and eradication programs will need to be modified (Wallner 1996a). Eradication programs are under increasing scrutiny (Myers et al. 1998);

hence, preventing the reintroduction of any gypsy moth biotype needs to be the first priority.

7. Social and political considerations: *High* (*RC*) (Applicable risk criteria: a, b, c, d)
The Asian gypsy moth has already demonstrated that it will have an impact on international trade with resulting political overtones. It is one of the most well-known forest pests that has moved successfully in commerce, and it is known to be associated with SWPM from several countries (Wallner 1996a). The major consequences are in forested residential areas where nuisance, esthetic, and recreational effects are most evident (Gottschalk 1990). Thus, additional introductions of this pest would be unacceptable to the general public (USDA Forest Service and APHIS 1995).

C. Pest risk potential: **High** (Likelihood of introduction = *High*; Consequences of introduction = *High*).

Nun Moth

Assessor—William E. Wallner

Scientific Name of Pest—*Lymantria monacha* Linnaeus (Lepidoptera: Lymantriidae)

Scientific Name of Hosts—A highly polyphagous defoliator, the nun moth prefers hosts in the genera *Abies, Acer, Betula, Carpinus, Fagus, Larix, Picea, Quercus,* and *Ulmus* (Grijpma 1989, Novak et al. 1976).

Distribution—Distributed throughout Europe and parts of Asia south of 60°N. latitude; within latitudes 43°–57° N., the nun moth occurs from Portugal to Japan. It is mainly a pest in central and eastern Europe from the Pyrenean Peninsula to the Balkans and throughout eastern Siberia to Vladivostok in the Russian Far East.

Summary of Natural History and Basic Biology of the Pest—The nun moth (*Lymantria monacha*) is a tree-killing species, and defoliating outbreaks in Europe have caused massive mortality to spruce, pine, and deciduous trees (Bejer 1988). It is a univoltine species whose outbreak periodicity has declined from about 30–40 year intervals to a 6-year frequency. Adults are vagile and active for 3–5 weeks from July to September, when they mate and deposit eggs in masses of 70 to 300 eggs. Embryonic development occurs over the next 2–6 weeks, and larvae inside the eggs enter diapause until spring (usually May), when they emerge from the eggs. Larvae require new foliage, and if unavailable, first and second instar larvae spin down on silken threads and can be transported considerable distances by the wind. Once feeding is initiated—on the basis of such factors as host type, condition, and weather—larvae develop through five to seven instars. Pupation usually occurs during July on the boles of trees, but in dense populations, pupae also are found high in tree crowns. Females live about 10 days, whereas males may live up to 24 days after emerging (Bejer 1988).

Caterpillars of nun moth are the only life stage that directly damage trees by consuming needles or leaves. The impacts of feeding on the tree vary: spruce cannot survive 70-percent defoliation and often are killed by 50-percent foliage loss. In the case of pine trees, mortality is not usually as serious because trees refoliate. Regardless of tree species, the risk of death is related to the retention of foliage; the fewer the number of years of foliage the species carries, the better it will survive defoliation (Bejer 1988).

Egg masses consist of naked clusters of orange-brown spherical eggs about 1 mm in diameter. Newly hatched larvae are about 4 mm long and tan but turn black in 24 hours. Larvae are not particularly distinctive until they reach third instar, when the orange head with black freckles and tan, green, or dark gray bodies become evident. When mature, larvae are 30–40 mm long and difficult to find because their color conceals them on the bark. Adult color is variable; chalk-white forewings with dark transverse lines and patches are the norm, but dark brown to black forms occasionally occur intermixed. The female has a wingspan of 45–55 mm, short sawlike antennae, and a pointed reddish abdomen with black spots. Males are smaller, having a wingspan of 35–45 mm, pectinate antennae, and gray-black abdomens (Novak et al. 1976, Ferguson 1978). The cryptic color of larvae makes larval detection at low densities difficult. Pupae are attached by a few threads to the bark or in the whorls of twigs, and their gray–brown bodies are easily observed. The most dependable means of detecting low densities is with the synthetic female pheromone of the gypsy moth: racemic disparlure. Traps baited with this lure can effectively be used for detecting and monitoring populations (Jensen and Nielsen 1984). Taxonomic identification of specimen material is possible (Novak et al. 1976, Ferguson 1978, Keena and Shields 1998), and comparisons of features with other Lymantriids can be made (Schaefer 1989); no genetic identification techniques using mitochondrial or nuclear procedures have been developed to identify nun moth biotypes.

The nun moth has a spectrum of natural enemies, including parasites, predators, and disease. Birds are recognized as most important in controlling eggs and larvae (Bejer 1988), and a baculovirus has been implicated in population collapses and has been cultured and applied for control purposes. However, it is not anticipated that there are comparable natural enemies waiting for the nun moth should it be introduced into North America. Synthetic pyrethroids and growth inhibitors as well as commercial formulations of *Bacillus thuringiensis* Berliner are routinely used to reduce nun moth populations in Eurasia.

Specific Information Relating to Risk Elements—

A. Likelihood of introduction

1. Presence with host or commodity at origin: *High* (*RC*) (Applicable risk criteria: b, c, d, e, f, g, h)
   A suite of Lymantriid pests continues as a forest threat (Lipa and Kolk 1995), and the accelerated frequency of outbreaks makes the nun moth even more threatening. The large geographical range, resilient life stages, and polyphagous feeding habits of this insect ensure that the nun moth will be affiliated with tree species commonly used in SWPM. Female attractancy to lights increases the risk that international trade can provide a pathway for introduction, as it has for Asian gypsy moth (Wallner et al. 1995).

2. Entry potential: *High* (*RC*) (Applicable risk criteria: b, c, d)
   Detection of eggs in cracks and crevices on bark, wood, and other objects is almost impossible. Regardless of when host material is sawed and utilized for SWPM, the resilient eggs can withstand translocation activities for a period of 6 to 9 months. Despite these potentials, no nun moth males have been taken in North America at extensive trap deployments for detection, eradication, and suppression programs for the gypsy moth. However, this may be misleading because racemic disparlure, which attracts male nun moths, has been replaced by +disparlure, which is unattractive.

3. Establishment potential: *High* (*VC*) (Applicable risk criteria: a, b, c, d, e, f)
   A history of pestilence over a wide geographic area in Eurasia provides evidence of nun moth adaptability. Although polyphagous, this moth prefers conifers but is capable of developing on deciduous trees (Lipa and Glowacka 1995). Forest regions of Canada, Mexico, and the United States have forest types susceptible to nun moth colonization; the climate is very suitable for this insect. More troubling is the abundance of acceptable hosts in most regions where international trade might provide pathways for introduction. Additionally, vagile females and dispersing first-instar larvae increase the potential for finding suitable host material requisite to colonization.

4. Spread potential: *High* (*VC*) (Applicable risk criteria: a, c, d, e, f, g)
   Long-distance spread is principally by the resilient egg stage that may be attached to bark or in bark crevices. Eggs are laid in clumps and glued together without any covering of female abdominal hair. They may be laid on items transported by people such as containers, pallets, forest products, or vehicles. The majority of dispersing first and second instar larvae are limited to distances of several hundred meters, although a small proportion have been reported to disperse more than 1–2 km. Adults of both sexes are mobile, and males are known to disperse up to 3,500 m. Flight distance of the female is somewhat limited until she deposits a portion or all of her eggs. Both sexes are attracted to artificial lights and are capable of ovipositing on containers and vessels in transportation centers such as ports and yarding areas (Wallner et al. 1995). Once the nun moth is introduced, its rate of spread by windblown larvae and flying females would be rapid. The nun moth could colonize a variety of hosts in North America that would ensure that redistribution would proceed until its entire potential range was achieved (USDA Forest Service 1991).

B. Consequences of introduction

5. Economic damage potential: *High* (*VC*) (Applicable risk criteria: a, b, c, d)
   Acknowledged as the primary forest enemy in eastern and western Europe, the nun moth has caused enormous losses despite chemical intervention (Sliwa and Sierpinska 1986, Bejer 1988). For example, in

Poland and Russia during the period 1853–63, some 403,000 km^2 of forests were destroyed by nun moth attack with a loss of 147 million m^3 of timber. During the period 1987–94, this moth caused significant tree mortality on more than 6.3 million ha; in 1993–94, more than 1 million ha required protection by chemical sprays in eastern Europe. The nun moth is considered the most serious pest threat to western and northern forests of spruce, pine, and Douglas-fir in the United States (USDA Forest Service 1991).

6. Environmental damage potential: *High* (*RC*) (Applicable risk criteria: a, b, c)
   As a tree killer, the nun moth can decimate vast forest regions and increase the risk of attack by other pests, notably bark beetles (Grijpma 1989). As a consequence, these regions are often converted to other uses such as agriculture (Bejer 1988), which in turn has substantive impacts on other life forms as these ecosystems are altered. Defoliation of more than 70 percent kills spruce; pines and deciduous trees are more resilient. Still, efforts to reduce damage rely on pesticidal sprays that will have deleterious effects on many nontarget organisms.

7. Social and political considerations: *High* (*RC*) (Applicable risk criteria: a, c)
   The past seriousness of nun moth outbreaks in Europe and the availability of suitable hosts and climate in North America impart a high degree of certainty of this insect's potential pestilence. Outbreaks of nun moth have increased with a severity and regularity that portend astronomical damage and protracted control costs. Destruction of entire forest ecosystems would be unacceptable to the general public and probably would result in irreversible ecosystem changes and costly eradication and suppression programs.

C. Pest Risk Potential: **High** (Likelihood of introduction = *High*, Consequences of introduction = *High*).

Purple Moth

Assessor—William E. Wallner

Scientific Name of Pest—*Sarsina violascens* Herrich–Schaeffer (Lepidoptera: Lymantriidae)

Scientific Names of Hosts—Various *Eucalyptus* spp. (Myrtaceae) but especially *E. cloeziana* F. Muell., *E. citriodora* Hook f., *E. nesophilia* Blakeley, *E. grandis* Hill ex Maid; *Psidium* spp. (Myrtaceae), *Mikania* spp. (Compositae), and *Osmanthus* spp. (Oleacae).

Distribution—This moth is widely distributed in Brazil from Rio Grande do Sul to the northern part of that country. The purple moth is most important in Brazil's central regions. It also has been reported defoliating *Eucalyptus* in various regions of Argentina, Peru, and Paraguay (Zanuncio et al. n.d.) as well as Mexico (C. Hodges, personal observation).

Summary of Natural History and Basic Biology of the Pest—*Sarsina violascens* belongs to the order Lepidoptera, family Lymantriidae, which includes numerous pest species from around the world (gypsy moth, nun moth, browntail moth, pine caterpillar, etc.). The name "purple moth" is assigned to this moth despite its apparently having two adult color phases, brown and the more common violet (Zanuncio et al. n.d.). It is not possible to discriminate between these color forms based on larval appearance because all larvae are light brown to beige. *S. violascens* is one of several lepidoptera endemic to Brazil's Myrtaceae that seriously defoliate introduced *Eucalyptus* (Berti Filho 1983, Zanuncio 1976). The genus *Sarsina* is considered neotropical with no known species north of Mexico (Ferguson 1978).

S. violascens, reported as a major pest in southeastern Brazil, also is found in Argentina, Peru, and Uruguay (Zanuncio et al. n.d.). In Brazil, adults are active from March to December, depending on the regional climate. The spherical, milky-white eggs are deposited singly or in 1 layer of up to 40 eggs on *Eucalyptus* leaves. In Mexico, egg masses were commonly found on the lower trunks of trees. Eggs in heavily infested areas were 90-percent parasitized, whereas those outside defoliated plantations were not parasitized (C. Hodges, personal observation). Embryonic development is completed in 11 days and larval development in 37 days. The brown–beige hairy larvae are voracious nocturnal feeders that congregate on the lower third of the tree trunks during the day. Pupation lasts 11 days and occurs on the leaves of dry branches, tree trunks, or understory plants. The humpbacked, reddish-brown pupae are 17 mm long for the male and 34 mm for the female (Zanuncio et al. n.d.). Although not stated in any of the literature reviewed, the purple moth is assumed to be univoltine, and its eggs are thought to be the sustaining intergenerational life stage as it is with other Lymantriidae.

In Brazil, *S. violascens* is one of the most important defoliators of plantation *Eucalyptus* (Zanuncio et al. 1992, Berti Filho 1983); populations fluctuate widely owing to control by parasites (E. Berti Filho 1998, personal communication). Trees are weakened by defoliation, their growth rate is reduced, and they are susceptible to further attack by secondary organisms. Clearly, this insect has been among the top five or six defoliators of plantation *Eucalyptus* in South America (Zanuncio et al. 1995. It also is on the potential quarantine pest list for Australian eucalypts (Floyd et al. 1998).

Specific Information Relating to Risk Elements—

A. Likelihood of introduction

1. Presence with host or commodity at origin potential: *High* (*RC*) (Applicable risk criteria: b, c, d, e, h) The large geographical range of this insect and its broad host range guarantee that it will be affiliated with *Eucalyptus* or other subtropical hardwoods. All life stages are found on the tree (eggs, larvae, and pupae on the foliage and eggs and larvae on the trunk, but pupae can be found anywhere on or off the

tree) (J.C. Zanuncio 1988, personal communication). Despite its high rating due to host affiliation, the purple moth tends to be episodic in its outbreaks within defined areas and apparently is susceptible to natural controls. However, its polyphagous habits ensure potential reservoirs on several subtropical hardwoods used in SWPM.

2. Entry potential: *High* (*RC*) (Applicable risk criteria: b, c, d)
Eggs or egg masses appear to be the major risk for providing entry and, because of their small size and color, would be difficult to detect. Little information is extant on this insect's bioecology, but it is likely that it will behave as other Lymantriids; oviposition sites will vary with little fidelity to a specific location. Evidence of this was reported for *S. violascens* (Zanuncio et al. n.d.) in rearing studies in which egg masses were deposited on flat sheets of paper rearing material. In general, Lymantriid adults are attracted to lights that can result in egg masses' being transported into the United States on nonhost material and vehicles (Wallner et al. 1995). A completely hatched Lymantriid egg mass, comparable in appearance to *S. violascens*, was found on the cut end of a *Eucalyptus* log in a Montevideo, Uruguay, port by members of the Wood Import Pest Risk Assessment and Mitigation Evaluation Team (WIPRAMET). It was not possible to determine how the egg mass got there, but this occurrence does demonstrate the egg mass pathway on sawed timber utilized as SWPM to be a worrisome one. Pupae can be found anywhere on the tree, but both sexes must survive and emerge concurrently to ensure a reproducing population. Late-stage larvae tend to rest on the lower trunk and can be transported, but the likelihood of successful translocation is believed to be low.

3. Establishment potential: *High* (*RC*) (Applicable risk criteria: b, d, e)
S. violascens is a polyphagous, neotropical species that has already demonstrated its ability to attack a new host—*Eucalyptus* (Zanuncio 1976). Thus, if the purple moth encounters a *Eucalyptus* species or another myrtaceous or oleaceous host, colonization is reasonably certain. Given that most Lymantriids are very mobile in the larval and adult stages, host finding would be aggressive. Hosts growing under cool, dry conditions would be most vulnerable to colonization (Zanuncio et al. 1994).

4. Spread potential: *High* (*RC*) (Applicable risk criteria: b, c, e, f, g)
Dispersability of Lymantriids has been well documented; both neonates and adults can be expected to disperse several hundred meters to a kilometer or more with each episode. Populations would be expected to expand rapidly following initial establishment (Zanuncio et al. 1991) and could be accelerated if adult females were attracted to artificial lighting.

B. Consequences of introduction

5. Economic damage potential: *Moderate* (*RU*) (Applicable risk criteria: a, b)
The impact of defoliation on plantation *Eucalyptus* in South America is poorly understood. Defoliation is likely to reduce vigor and growth, temporarily despoil the appearance of trees, and weaken them, making attack by other organisms more likely. Perhaps the biggest impact would be on the U.S. *Eucalyptus* foliage industry, although it is not known if *S. violascens* attacks *E. globulus* Labill. or *E. pulverulenta* Sims.

6. Environmental damage potential: *Moderate* (*RC*) (Applicable risk criteria: d)
Because *S. violascens* is an episodic defoliator, its damage would not be expected to be protracted. In South America, populations are regulated by natural enemies (Zanuncio and de Lima 1975). If this moth were introduced into the United States, it is not known if its dynamics would change in the absence of these natural controls. This could necessitate application of chemical controls thus presenting an environmental hazard. One bothersome feature of *S. violascens* is its polyphagy, which could seriously impact U.S. forest and plant ecosystems other than *Eucalyptus*.

7. Social and political considerations: *Moderate* (*RC*) (Applicable risk criteria: a)
   Most Lymantriid moths are outbreak species and periodically tend to be numerous. *S. violascens* has caused localized defoliation in Brazil (hundreds of hectares) (Zanuncio and de Lima 1975). Defoliation would reduce growth rates and should not kill *Eucalyptus* but could be esthetically unsightly. The major impact would be on high-value urban plantings and those used for the floral industry. A major unknown is the impact on other trees or shrubs because *S. violascens* is so polyphagous.

C. Pest risk potential: **High** (Likelihood of introduction = *High*; Consequences of introduction = *Moderate*).

La Grilleta

Assessor—William E. Wallner

Scientific Name of Pest—*Pterophylla beltrani* Bolivar y Bolivar (Orthoptera: Tettigonidae)

Scientific Name of Hosts—*Acacia farnesiana* (L.) Willd., *Acer negundo* L., *Cordia boissieri* D.C., *Cornus florida* L., *Juglans mollis* Engelm., *Platanus occidentalis* L., *Prosopis glandulosa* (Torr.), *Quercus virginiana* Mill., *Quercus* spp., *Ulmus divaricata,* and *Pinus* spp.

Distribution—*Pterophylla beltrani* is known to occur only in limited regions of the Mexican States of Nuevo León and Tamaulipas. However, another lesser known species, *Pterophylla baezi* Bolivar and Bolivar, has been recorded from Guerrero and Michoacán States (Cibrián Tovar et al. 1995).

Summary of Natural History and Basic Biology of the Pest—*Pterophylla beltrani* belongs to the order Orthoptera, family Tettigonidae. There are some 4,000 species of Tettigonids or long-horned grasshoppers, many of which are tropical or subtropical in origin. *P. beltrani* attacks a broad range of hosts, some of which are present in North American temperate forests (Cibrián Tovar et al. 1995). The first record of its appearance was the outbreak in 1981–82 on over 200,000 ha. In regions of Neuvo León and Tamaulipas States (Góngora–Rodríguez et al. 1989), it caused severe defoliation for 2–3 years, but, since then, populations in the Sierra Madre Oriental have declined in intensity.

La Grilleta, known colloquially as the "Queen of the Crickets," is a defoliating insect most commonly found in oak and mixed oak forests of 600 to 1,800 m in elevation. It has been reported as a problem principally in one region of northeastern Mexico. Nymphs and adults consume the foliage and, in dense populations, bark and cambial tissue of shoots and branches. This causes reduced growth and occasional death to portions of, or entire, trees. The location of the infestation also affects economic impacts; high-value forests, those adjacent to agricultural cultivation, especially fruit orchards and populated areas, are most affected economically.

Although *P. beltrani* is acknowledged to be the most documented of South American Tettigonid pests, at least two others are known from other regions. In the Mexican States of Guerrero and Michoacán, *P. baezi* is known, but its hosts are not. Still another Tettigonid species, *Coniungoptera nothofagi* Rentz & Gurney, was observed in 1995 defoliating about 800 ha of *Pinus radiata* in the foothills of the Andes Mountains near Chillan, Chile (R. Billings, personal observation). The insect, which normally feeds on native hosts, demonstrated its polyphagy by switching to this exotic pine species. The behavior of these two Tettigonid species is not completely known; however, should they behave similarly to *P. beltrani* and oviposit in tree species commonly used for wood packaging or dunnage, they would constitiute a serious threat.

Long-horned grasshoppers, although present in most regions of the United States, are seldom numerous enough to cause tree damage. Some, like the Mormon cricket, *Anabrus simplex* Haldeman, are periodically abundant and destructive to cultivated crops. During heavy migrations, crickets invade and damage fringe-type ponderosa pine. The true katydid, *Pterophylla camellifolia* (F.), dwells in colonies in dense forests of the Eastern and Central United States but seldom causes serious damage (Craighead 1950). Contrarily, in Mexico *P. beltrani* recently has emerged as a perennial pest of oak and other hardwoods. It is univoltine. Eggs are laid in the bark during July–October and remain unhatched, probably in diapause, until March of the following year. Hosts preferred for oviposition are oak, walnut, and pine. Eggs are laid 2–3 cm deep within the bark along the bole in clusters of 4–10 eggs. Not all eggs hatch in 1 year; some remain in diapause for 1–2 years. After hatching from eggs, nymphs tend to be colonial and move to the new foliage to feed. Development is completed by July–September, and adults disperse not by flying but by gliding up to distances of 100 m.

Specific Information Relating to Risk Elements—

A. Likelihood of introduction

1. Presence with host or commodity at origin: *Moderate* (*MC*) (Applicable risk criteria: b, e, g, h)
   Packing materials made of pine or oak with the bark still attached would transport eggs. Harvesting in Mexico normally is done from October to May, and standing trees would be available for ovipositing females during July–September. The opportunity for infestation by ovipositing females would be increased when conifers and hardwoods are growing in admixture.

2. Entry potential: *High* (*RC*) (Applicable risk criteria: b, c, d)
   The eggs would be deposited deep within the bark, making detection virtually impossible. Protracted diapause by eggs (for 1–2 years) increases the likelihood of survival in bark on pallets or wood packing materials during and after shipment and perhaps from bark that is removed.

3. Establishment potential: *High* (*VC*) (Applicable risk criteria: b, c, f)
   Because this species is known to attack a broad spectrum of deciduous hosts, both subtropical and temperate, it could find acceptable hosts in Western and Southern U.S. locations and protectorates. Although natural dispersal is limited, the breadth of hosts utilized is not. This suggests that, if introduced, this species could become established in oak and pine forests of the Southern United States, where oaks and pines grow in admixture.

4. Spread potential: *Moderate* (*RC*) (Applicable risk criteria: c, e, g)
   The aggregation tendencies at low-population densities and the limited vagility of nymphs and adults (less than 100 m) would lead to slow natural spread. However, spread could be accelerated by humans moving SWPM with bark containing eggs. Bark removed from sawed wood and used for mulching and similar purposes, would also constitute a threat for spreading populations.

B. Consequences of introduction

5. Economic damage potential: *Moderate* (*RC*) (Applicable risk criteria: a, b, c)
   In Mexico, this insect is a defoliator of hardwoods that currently are of little economic value. However, this insect weakens and kills trees and has proven problematic in urban and agricultural regions to the extent of necessitating routine pesticidal action. Oaks are an important, limited resource to the U.S. Southwest and Midsouth. These trees could be threatened by this insect, which could alter tree vigor and invite organisms of secondary attack to become more aggressive. Sclerophyllous forests of California, the mountainous regions of Arizona–New Mexico, and the oak and pine forests of the Southeastern United States appear to be suitable climatic regions and habitats for this insect. Economic damage would be through growth loss and accelerated mortality to oaks. Such losses might be acceptable in southern pine-producing areas, where oaks are not featured, but unacceptable in other regions where oak may be the dominant tree species with high economic or ecological value. Another important economic consideration is the ability of the insect to infest agricultural crops such as corn, grains, citruses, walnuts, and peaches.

6. Environmental damage potential: *Moderate* (*RC*) (Applicable risk criteria: e)
   This species is unlikely to cause extensive tree mortality. However, owing to the sheer number of La Grilleta during an outbreak, the nuisance they cause to residents of urban areas and the damage to urban plantings may prompt control measures with possibly negative environmental consequences. The esthetics of forests, urban forest regions, and associated fruit- and nut-producing regions could be seriously impacted.

7. Social and political considerations: *Moderate* (*RC*) (Applicable risk criteria: a)
   Defoliation will have only modest mortality impacts on oaks and other hardwoods. The impact on pines

would be minimal in the case of *P. beltrani*. However, lesser known tettigonids that have been reported to defoliate *Pinus radiata* D. Don in Chile could cause serious growth loss and perhaps tree mortality. There is the risk that, if established, such insects could become serious nuisance pests in agricultural and urban regions. Although *P. beltrani* infestations appear to be restricted to limited forested regions in Mexico, this species' status as a perennial problem and the abruptness of its recent occurrence give reason for concern as a potential introduced pest.

C. Pest Risk Potential: **Moderate** (Likelihood of introduction = *Moderate*; Consequences of introduction = *Moderate*).

Sapsucking Insects

Pine Flat Bug

Assessor— John D. Lattin

Scientific Names of Pest—*Aradus cinnamomeus* Panzer (Hemiptera: Heteroptera: Aradidae).

Scientific Names of Hosts—*Alnus glutinosa* (L.) Gaerin, *Betula alba* L., *Juniperus* spp., *Larix siberica Ledh.*, *Picea abies* (L.) Karst, *Pinus banksiana* Lamb., *Pinus nigra* Arnold., *Pinus sylvestris* L., *Salix* spp. Potential hosts in the United States include *Cupressus sargentii* Jeps., *Pinus attenuata* Lemm., *Pinus banksiana* Lamb., *Pinus clausa* (Chapm. ex Engelm.) Vasey ex Sarg., *Pinus contorta* Dougl. ex Loud., *Pinus contorta bolanderi* (Parl.) Vasey, *Pinus contorta latifolia* Engelm., *Pinus contorta murrayana* (Grev. & Balf.) Engelm., *Pinus jefferyi* Grev. & Balf., *Pinus lambertiana* Dougl., *Pinus monticola* Dougl. ex D. Don., *Pinus nigra* Arnold., *Pinus ponderosa* Dougl. ex Laws., *Pinus radiata* D. Don., *Pinus resinosa* Ait., *Pinus sabiniana* Dougl., *Pinus strobus* L., *Pinus sylvestris* L., *and Pinus virginiana* Mill.

Distribution—*Aradus cinnamomeus* is widely distributed in the temperate regions of the Old World.

Summary of Natural History and Basic Biology of the Pest—*Aradus cinnamomeus* Panzer belongs to the Hemiptera: Heteroptera, family Aradidae. These insects are called flat bugs because of their greatly compressed bodies, which is a condition that enables them to get under bark with relative ease. Species of this family are widely dispersed in the world and are represented by about 211 genera and 1,800 species (Schuh and Slater 1995). Their peculiar appearance has long attracted the attention of naturalists. Adults may be fully winged, short winged, or even wingless (Usinger and Matsuda 1959). Many species are known chiefly from field-collected adults and nymphs; a smaller number have biological information available.

Species are most commonly found on trees—under bark, or on fungi on dead or dying trees—whereas others are found in the dense litter layers of subtropical and tropical forests where fungi are abundant. Most known species feed on fungi, for the modified, coiled mouthparts of these insects assist them in reaching fungal tissues. There is an exception—the feeding habits of *Aradus cinnamomeus,* a small (3.5–4.5 mm) species well documented as feeding on the living tissues of young pine trees (Strawinski 1925, Tropin 1951, Usinger and Matsuda 1959, Southwood and Leston 1959, Rozhkov 1966). *Aradus cinnamomeus* is a well-known pest of pines in the Palearctic (especially *Pinus sylvestris*), occurring from Great Britain (Carayon 1955, Southwood and Leston 1959, Leston 1951a,b) to Siberia (Rozhkov 1966). This species is found on other Old World conifers as well. Roshkov (1966) stated that this species was a serious pest of pine trees in the European USSR but occurred rarely on larch in Siberia. This insect species was listed as a potential pest that could be imported from the former Soviet Far East (USDA Forest Service 1991).

Southwood and Leston (1959), citing Strawinski (1925), outlined the biology of this insect as follows: Eggs deposited under the bark of pine trees in the spring, hatching in about 4 weeks. The first year is spent as nymphs on young trees. These nymphs hibernate the first winter near or on the trees. The following year, the adult stage is reached, and the insects mate and lay eggs. The life cycle in eastern Europe lasts for 2 years with nymphs and adults hibernating together (Strawinski 1925, Tropin 1951). Southwood and Leston (1959) felt that there was only a single generation each year in Great Britain. Usinger and Matsuda (1959) discuss the biology of this species as well. Southwood and Leston (1959) noted that *A. cinnamomeus* occurred in several morphological forms: females that were fully winged or short-winged (brachypterous) and males that had extremely narrowed forewings (exhibiting stenoptery) and the hind wings usually reduced. Without citation, they indicated that "a tachinid parasite had been reported from Germany." Tanada (1959) discussed the use of a fungus that provided some control of this species, as did Franz (1961).

There are two native species of Aradidae found in the United States and Canada that closely resemble *Aradus cinnamomeus* Panzer: *A. antennalis* Parshley and *A. kormilevi* Heiss. For many years, these species were considered to be the same as the European *A. cinnamomeus,* and thus all references to the North American species were found under the European name until Heiss (1980) provided clear proof that, in fact, three species were involved. His article provided ample documentation of the distinctiveness of the three taxa. The true *A. cinnamomeus* is not yet found in North America. The two closely related species, *A. antennalis*and *A . korimelivi*, are widespread throughout much of North America (Froeschner 1988; Furniss and Carolin 1977; Heiss 1980; Larochelle 1984; J.D. Lattin, personal observation; Parshley 1921) and are found on a wide variety of pine hosts (Evans 1983; Larochelle 1984; J.D. Lattin, personal observation; Matsuda 1977; Usinger and Matsuda 1959). This indicates the potential for introduction and spread of the nonindigenous *A. cinnamomeus* from the Palearctic Region, where it is regarded as a serious pest of pine. In the United States it might become a pest of other trees as well as the pines.

Specific Information Relating to Risk Elements—

A. Likelihood of introduction

1. Presence with host or commodity at origin potential: *High* (*VC*) (Applicable risk criteria: c, d, e, f, g, h)
This insect is widely distributed in the Palearctic region from the United Kingdom to Siberia. The insect is found under the bark of trees, hibernates as an adult or nymph (often under bark), and is an ideal "hitchhiker" on untreated wood, especially when bark or bark fragments are still attached. This is a small, very inconspicuous insect that is easily overlooked by the observer, for it often resembles a tiny bark chip and is a likely organism for transport. The chief host in the Old World is *Pinus sylvestris*, but it is known on other conifers (e.g., *Larix*).

2. Entry Potential: *High* (*VC*) (Applicable risk criteria: b, c, d)
This is a small, cryptic insect that is easily overlooked in inspections. Both nymphs and adults would be found on and under the bark of untreated wood. This insect is unlikely to be dislodged from activities associated with handling and shipping. It is inactive at low temperatures and thus able to be transported with ease.

3. Establishment potential: *High* (*VC*) (Applicable risk criteria: a, b, c, e, f)
Because of its feeding habits, *A. cinnamomeus* is a potential pest of pines everywhere, particularly in plantations or in regenerating stands. The Northern Hemisphere, of course, is where most of the pine species occur naturally (Little [1979] reported 45 native species, subspecies, and varieties of pines in the United States), and thus risk of establishment would be high (Lattin and Equihua-Martinez 1996). Pines occur along much of the coastlines of the Eastern, Western and Southern United States, providing many opportunities for colonization in regions around ports and beyond. Virtually every pine species in North America would be a potential host. *Pinus sylvestris*, a primary host species ranging from Great Britain (Leston 1951a) to Siberia (Roshkov 1966), has been planted widely in the United States. *Pinus resinosa* (red pine), a close North American relative to *P. sylvestris*, is widely distributed in Eastern North America. Kiritshenko (1955) also cited *Juniperus, Alnus, Betula,* and *Salix* as hosts. Leston (1951a,b) documented the establishment of *A. cinnamomeus* in the United Kingdom.

4. Spread potential: *High* (*VC*) (Applicable risk criteria: b, d, e, f, g)
There are many species of the family Pinaceae in the United States (Little [1979] indicates over 60), and many are found around our ports. Quite literally, the pine flora extend from coast to coast (e.g., *Pinus contorta—Pinus banksiana—Pinus virginiana* and *Pinus clausa*). Many other prominent species occur as well (e.g., *Pinus ponderosa, P. monticola, P. radiata, P. jeffreyi, P. lambertiana*), and, of course, many pine species are often grown in plantations throughout the Southern United States. The dispersal capabilities of the insect are dependent largely on the female because this is the form that is fully winged. The fertilized winged female would be able to disperse with ease. The natural occurrence of this species

throughout much of the Holarctic demonstrates the capacity of this species to spread and become established. Likewise, the native counterparts, *A. antennalis* and *A. kormilevi*, have a wide distribution in the United States and Canada, again testifying to their ability to disperse.

B. Consequences of introduction

5. Economic damage potential: *High* (*VC*) (Applicable risk criteria: a, b, c, d)
   A. cinnamomeus is a documented pest of pines in the Old World that feeds directly on young trees and is likely to feed on similar stages of our native pines. Any regeneration site or plantation, including timber and Christmas tree production, would be particularly vulnerable. This likely would include the various pine species grown widely in the Southern United States and native pines throughout North America. Contrary to most Aradidae, this species feeds on the plant itself rather than on fungi.

6. Environmental damage potential: *High* (*VC*) (Applicable risk criteria: a, c, d)
   A. cinnamomeus causes damage to seedlings and young trees, resulting in reduction in tree regeneration. Damage is likely to be particularly serious where even-aged stands are being regenerated. This insect could attack species of highly restricted distribution or widespread species, resulting in extensive disruption of biological diversity.

7. Social and political considerations: *High* (*VC*) (Applicable risk criteria: a, b, c)
   A. cinnamomeus may cause interruption and disruption of efforts to develop and maintain even-aged stands for wood and fiber, disruption and damage to natural landscapes in which pines are a particular component (throughout much of the country), and damage to pines being used for landscape purposes. Because *Pinus sylvestris*, the insect's common host tree in the Old World, has been planted so widely for decoration, windbreaks, or Christmas tree production, these trees would be likely candidates for concern. Efforts at reforestation might well be impacted because the insect feeds on seedlings and young trees. Given the widespread occurrence of plantations of Monterey pine (*Pinus radiata*) in the Southern Hemisphere (Ohmart 1982), imposition of phytosanitary restrictions on shipments of materials possibly infested with the pest are likely for those countries (e.g., Chile, New Zealand, Australia, South Africa).

C. Pest risk potential: **High** (Likelihood of introduction = *High*; Consequences of introduction = *High*).